PERIODICAL
UNIVERSITY OF HAWAII
LIBRARY

OUTLOOK ON AGRICULTURE

Volume III Number 2

Summer 1961

3

The design in linocut on the cover is a composite of drawings from two medieval manuscripts. In the centre is a figure from the works of Matthew Paris, who entered St. Alban's as a monk in 1217. Surrounding this, depicting farming activities throughout the year, are drawings based on MS. from the Benedictine Abbey of Sweifalten, circa 1162.

Articles published in this journal are the copyright of Imperial Chemical Industries Limited. Permission for their reproduction may be granted on application to the Editor.

OUTLOOK ON AGRICULTURE

VOLUME III · SUMMER 1961 · NUMBER 2

PAGE

54 *Editorial: More Milk and Meat from Grass*

55 *The Development of Farm Management in Great Britain*
E. A. ATTWOOD, M.A.

62 *The Conservation of Soil Fertility in Tropical Plantations*
T. EDEN, D.Sc., F.R.I.C.

69 *Pollination of Field Beans*
W. A. SCRIVEN, N.D.A., N.D.D., C.D.A.,
B. A. COOPER, B.Sc., F.R.E.S., and H. ALLEN, N.D.B.

76 *Avoidance of Drift from Airborne Sprayers*
R. J. COURSHEE, B.Sc.(Gen.), B.Sc. (Physics)

81 *Blister Blight Disease of Tea*
G. B. PORTSMOUTH, B.Sc. (Hons.), A.R.C.S., D.I.C.

89 *Facial Eczema of Sheep and Cattle in New Zealand*
C. P. MCMEEKAN, B.Agr.Sc., Ph.D.

97 *Book Reviews*

Communications should be addressed to the Editor, E. J. McNaughton, B.Sc. (Hons.), B.Sc. (Agric.), Imperial Chemical Industries Limited, Jealott's Hill Research Station, Bracknell, Berkshire, England

MORE MILK AND MEAT FROM GRASS

It is well known that the chief cause of malnutrition in many of the underdeveloped countries is a lack of protective foods, especially protein-rich food of animal origin. Indeed, if the world's diet is to be brought up to a reasonable level by the end of this century the present output of animal products will have to be trebled—and presumably more than trebled in lands where the population rise is most rapid and nutritional deficiencies are greatest.

Much of this protein must come in the form of meat and milk from grazing animals, and we look first to grassland for any increase in supply. There is certainly great scope for improvement. Dr. W. Davies recognizes five global pastoral systems or nutritional environments within which grassland supports from 80 cattle units per 100 acres in the "very intensive" to only 5 in the "very extensive," and milk yields range from 860 to 42 gallons per cow. Nearly 5000 million acres, or 86·4 per cent, of the world's grassland carry under 20 cattle units per 100 acres, and about half of the total livestock are maintained in the tropics to 30° N and S of the equator. Such differences, Dr. Davies is convinced, are nutritional rather than genetic or climatic, and upgrading depends on improving the quality of the grazings. The potentials usually offer a fourfold increase in output, but without soundly planned research there is no likelihood of any material gain.

With these conclusions there will be general agreement. The practical issue, however, is whether output in the underdeveloped countries can be expanded rapidly enough to keep the populations well fed and in good health. We tend to see events telescoped in time, like the unfolding of a flower in a time-lapse film. Migratory grazing gives place to ranching. Nomads settle down. Fields of natural grassland are enclosed, thus concentrating the dung and building up soil fertility. Land comes under the plough and mixed farming begins, at first near villages and town markets and then further afield as transport advances. Better pasture plants are introduced, and herbage is conserved for out-of-season feeding. Meanwhile animal diseases are controlled and breeds improved. Eventually there is plenty of milk and meat for all. It is a pleasing picture.

In fact, however, there are formidable barriers to progress. In most tropical lands herdsmen and peasants live in a state of hunger, poverty and ignorance. Little is known about animal husbandry and next to nothing about grassland and its management. Although much could be achieved merely by applying the principles of good husbandry, there are too few agricultural officers to show the way. Moreover, knowledge acquired in temperate lands does not always apply in the tropics, and numerous problems can only be solved locally by long-term research. As a rule, advancement awaits social and political changes and general economic development.

Environmental conditions are often unfavourable for grass growth. Aridity is a limiting factor in such regions as the Middle East, North Africa and North Australia, where, at best, the desiccated pastures provide a bare sustenance only for part of the year. Here improvement depends chiefly on water supply and on the introduction of drought-resistant grasses and palatable legumes that fix nitrogen efficiently. In regions of better rainfall speedier progress may be expected, notably in equatorial Africa, where malnutrition is rife; but problems in monsoon Asia are difficult to solve. Agriculture is settled into systems of continuous cropping, and pressure of population compels use of the land for food crops, leaving little to spare for grazing. Cattle are used for draught, grazed on waste places and foddered on crop residues. Diets are essentially vegetarian. With the major exception of India, which has far too many cattle, much of the needed protein must be obtained from sources other than milk and meat.

Nearly everywhere the growth of grass is restricted to certain seasons, and, even if pastures are greatly improved, extra feed will have to be provided by growing fodder crops on suitable land. The possibilities of soiling in an equatorial climate have been strikingly demonstrated in Malaya, where elephant grass (*Pennisetum* sp.), grown in ridges and cut in 11-day rotations, yielded up to 100 tons of fresh grass per acre per annum. This method can be employed with advantage wherever fodder crops outyield pasture plants, and may sometimes be the main way of feeding livestock in difficult environments.

A great deal is being done by the F.A.O. to lay the foundations for increase in the supply of meat, milk, eggs, fish and other protective foods, and there will be a stocktaking of the results of five years' effort at a World Food Congress to be held in Rome in 1963. It will then be easier to determine what success the underdeveloped countries are likely to achieve in their efforts to banish hunger and disease.

THE DEVELOPMENT OF FARM MANAGEMENT IN GREAT BRITAIN

E. A. Attwood

(*The Agricultural Institute, Dublin*)

Early in the 1950*s it became the aim of government policy in Britain to achieve a more economically efficient agriculture, and farm management was developed into a service of practical use to farmers. Its methods are now being increasingly applied by specialist officers in solving the economic problems involved in the reorganization of the farm business and in helping farmers to use their land, labour and capital to best advantage.*

Farm management as a separate subject within the broad framework of agricultural knowledge is essentially an application of economic theory to the rational planning and operation of the individual farm. As such, it has stemmed from the analysis of the individual business unit put forward by economists of the late nineteenth century. The fundamental problems of economic organization, in this analysis, arose from the need to equate marginal increments of additional resources and the consequent increase in output in such a way that the profits of the individual business could not be improved by any reorganization of its policy.

In practice the search for the theoretically optimum level of output for any farm, and the appropriate combination of the available productive resources needed to achieve it, has been very much restricted. The direct application of economic laws to the running of a farm business has been limited by the difficulties of attaching numerical values to the non-linear functions produced in the theoretical text books, and also to the unwillingness of outside investigators to make a close examination of the costs and returns of individual farmers. Nevertheless, the growing complexity of agricultural techniques available to the farmer has greatly increased the variety of ways in which a farm can be organized. As the pattern of farm output began to change rapidly in the early years of the twentieth century, so the interest shown in the economics of farming grew, not only at the national level, but at the level of the individual farm.

THE START OF FARM MANAGEMENT WORK

By 1910 the work of collecting economic data from samples of farms was well under way in the United States. The Office of Farm Management, set up in 1902 within the United States Department of Agriculture, had already considered the problems of economic surveys, the first handbook on farm management had been published [29], and the subject was being taught in American agricultural colleges. Shortly before the First World War these ideas moved across to Britain. The Agricultural Economics Research Institute was founded at Oxford in 1913. Even prior to taking up his post, its first Director, C. S. Orwin, "had been interested in the application of cost accounting to the problems of farm management" [27], and within a few years of his appointment produced standard texts on the difficulties involved in farm accounting.

The growing interest of the Government in the business policies followed by the British farmer, during and immediately after the 1914–18 war, led to an extension of costings schemes, financed out of State funds. Direct grants for this purpose were made by the Ministry of Agriculture in 1923, and Advisory Economists were appointed to supervise the work, one of their functions being "to assist the less progressive farmers to improve their efficiency" [3]. In the following years the number of centres which undertook work in farm economics was increased, and the foundation of the Advisory Agricultural Economics Service was laid.

During this period almost the whole of the attention of the Advisory Economists was given to the production of full cost accounts, and to the development of the appropriate techniques for this work. As more experience was gained the limitations of full cost accountancy as an aid to management became increasingly obvious: it was very expensive in research staff; it involved the farmer in a considerable amount of detailed accounting; arbitrary assumptions in the distribution of some of the major cost items were unavoidable. It was with these problems in mind that Dr. R. McG. Carslaw went to America in the late 1920s to study research techniques in farm management, especially the survey method of collecting financial and economic data from a relatively large number of farms.

Growth in 1920–50

Dr. Carslaw's report on this system [14] was the basis of its introduction at Cambridge in 1931. The results of the Cambridge surveys of East Anglian farming were published annually in the early 1930s; these reports included data on factors influencing the profitableness of individual farms, and gave a much more useful guide to the farming policies which actually realized higher profits than did the results of the cost accounting work. Subsequently, this type of survey was extended to cover the whole of England and Wales, and a series of "Farm Management Surveys" has been undertaken annually since 1936.

Although this Management Survey has become the most important single undertaking of the Advisory Economics Centres, it does not give details of the costs incurred and profits realized by the output of each individual farm enterprise. In order to provide this information separate enterprise studies were made at each of the university departments. For the most part, these were originally undertaken without any form of centralized co-operation, each centre studying the costs of the products it felt to be of local importance. A notable exception was the Milk Investigation Scheme, which was started in 1934 and was sponsored by the then newly created Milk Marketing Board. This scheme covered about 600 farms in all parts of England and Wales, and the results, like those of the Farm Management Survey, were initially analysed and published by the Agricultural Economics Research Institute and subsequently by the Ministry of Agriculture.

Of the many other enterprise costs produced, perhaps the one most worthy of note was the Food Recording Scheme for Pigs; this was started at Cambridge in 1936 to obtain both physical and economic results of pig production and, even as late as 1954, provided the main source of information on the commercial management of pigs in Britain [5]. The wide variation apparent in the costs and efficiency in commercial herds has been the outstanding feature of this investigation, and its results have been an important factor in the decision to take steps to improve the overall food conversion rates in our national pig herd.

Thus, by the end of the 1930s there had grown up a system by which the Advisory Economic Centres were undertaking research into the management both of a fairly large sample of farms and of individual enterprises, and were producing a steady stream of reports for the different regions. Although the official view was that this material was used for advising farmers on efficient farm management [1], there was, in fact, no organized method of ensuring that farmers were aware that farm management advice was available, nor were the reasons for poor economic results on particular farms analysed in any systematic way.

These costing schemes became of great value when, in 1940, the Government first took over the responsibility for the prices of the main agricultural products produced in this country. The use of the Agricultural Economics Research Centres as collectors of the data, on which price fixing and other aspects of agricultural policy were based, meant that the extent to which this material was employed for specifically farm management purposes diminished considerably.

The decade of the war and post-war emergency saw a dramatic change in farming prosperity, owing to the need for maximum production from home resources, and the adoption of prices which were set at levels designed to encourage a very high rate of expansion. In these circumstances the problem of achieving an optimum level of output at which the maximum economic efficiency would be secured became of relatively little importance, and the emphasis of all advisory and research work was on the technical problems of a higher output. It was not until this emergency period began to pass that the farm economist regained his position as a source of information and advice of direct benefit to the farmer.

Developments in the 1950*s*

With the ending of the world food shortage, the emphasis in government policy veered away from further increases in output and towards achieving a more economically efficient agriculture, and agricultural prosperity became more dependent on reducing the costs per unit of output than on consecutive annual rounds of price increases. By 1954 the Government [4] was putting forward a policy aimed at securing a progressive improvement in efficiency that would provide a basis for steady reductions in the cost of supporting agricultural prices to the Exchequer, and this certainly placed farm management work in a much more important position.

Steps were also taken to see that help from trained advisers was available on the economic problems involved in running a farm business. In 1950 Dr. S. E. Johnson of the U.S. Department of Agriculture was commissioned to make a survey of agricultural economic research and advisory work in Britain. His report was not published, but it is referred to in some detail in a review of the work of six American farm management experts who subsequently visited Britain in the early 1950s [25]. Although none of the final reports of these visiting experts was published, one of them, Professor Karl T. Wright, in a paper given during his visit, included a list of the "Steps in Advance Planning of Research Studies in Farm Management" [32] which reflects the trend then current in America of concentrating on research methodology, rather than on the findings of the research itself. A comparison of this paper with that of W. Heath, Provincial Economist at Nottingham at that time [18], shows very clearly the differences in the approach to farm management made by the American and British economists. In Britain the research programme of the farm economists has always been dominated by the immediate needs of the farmer; as late as 1950 each farm case was taken as a unique problem, in which certain general principles of maximizing profit were involved, but not lending itself to a formal analysis in specific terms.

Emergence of a Farm Management Advisory Service

The next few years, however, saw the rapid development of a more formal approach to the subject. The most important change was the appointment in the early 1950s of relatively senior agricultural economists as Farm Management Liaison Officers, responsible for advisory work and research in farm management, at each of the Provincial Agricultural Economic Centres. Their chief function was to co-operate with the official advisory services in training and assisting the general advisory officers in their task of advising the individual farmer on the economic performance of his farm. This programme was co-ordinated by Mr. Arthur Jones, who was appointed Chief Farm Management Officer at the Ministry of Agriculture.

These events meant that farm management began to grow into a specialized and independent branch of agricultural economics, providing a worthwhile service to the farmer. Perhaps the nature of this change can be seen from the fact that, even as late as 1949, a conference on "Management in Farming" organized by the official advisory service included no paper on the economics of the organization of the farm business by any farm management specialist [2]; yet only five years later a training course on "Farm Planning and Budgeting Services in Farm Management Advisory Work" held by the O.E.E.C. in the United Kingdom was based on the experience gained in this country by a large group of economists and agriculturists who were concerned particularly with the measurement and improvement of economic performance at the farm level [7]. The report on this course contains a comprehensive range of papers on the practical uses of the various tools in farm management advisory work.

THE DEVELOPMENT OF FARM BUSINESS "STANDARDS"

In particular, this report shows the extent to which the development of farm management analysis in Britain was dependent on the study made by C. H. Blagburn [12]. His analysis of the factors that determine the level of profitability actually realized by farms within any size or type group was carried out on the results of those farms in Southern England which co-operated in the Farm Management Survey, but the basic principles on which it rested were soon applied in other centres. Fundamentally, this analysis requires the assumption, which has been repeatedly justified by many surveys, that the prosperity of a farm is very closely correlated with its level of production. For the majority of unprofitable farms, therefore, an improvement in their results depends upon analysing the causes of their relatively low output. Farm output is, in fact, dependent on two factors: the level of yields realized and the intensity of the farming system. Blagburn's main contribution to further development was a method of differentiating between the results of these two factors, especially his introduction of the *system index* and the *yield index*.

The system index is based on the production, in money terms, which a farm would achieve if each of its individual enterprises operated in such a way that it realized average yields. In other words, it is an attempt to evaluate the production programme of a farm with yields held constant. The index is calculated by multiplying the acreage of crops grown for sale and the numbers of livestock of each type by a "standard value" (which is the average value of the output of each in the area concerned). The total of these standard values is then divided by the effective acreage of the farm (e.g. the total acreage, less any land used for roads, buildings, waste, etc.), and an index of the intensity of the farming business can be derived by comparing this figure with the average of similarly computed figures for a group of farms of a comparable size and type. Once this is done, the yield index can be easily calculated by relating the actual output of the farm in question to the total "standard output" at average yields. Further, both the system index and the yield index can be calculated for cash crops and livestock separately, if such an analysis is required.

Blagburn's results have been criticized, especially by Rasmussen [28], on the grounds that they were prejudiced by the element of luck, i.e. that the farms which had a good year (relative to their own average performance) tended to be in the higher output and profit group, whereas the "unlucky" ones were to be found in the lower output and profit group. Nevertheless, the principle of analysing output according to the system and yield factors became widely accepted as an integral part of farm management work in Britain. Recently, however, there has been something of a swing away from this approach. The indices developed by Blagburn are only meaningful when compared with those for groups of similar farms, and in practice the problem of defining farm groups in such a way as to make valid comparisons possible has proved very difficult. Although much work has been put into the economic classification of British farms, no entirely satisfactory answers have yet been reached.

Measurement of the Efficiency of the Use of Farm Resources

On the input side the performance of a farm cannot so readily be evaluated by overall indices, and measurement of the efficiency of the use of the various inputs has been on an individual basis. Particular attention has been focused on the costs of labour and feedingstuffs, as these represent the two most expensive resources used on the national farm. The conventional analysis of labour costs and efficiency stems primarily from work done at Cambridge. The two important criteria are the financial one of output per £100 of labour used (including family labour) and the physical one of labour requirements for the farming programme, measured in terms of the man-days required for the various enterprises of the farm in relation to the total man-days which are actually worked. This latter index has been based on work in the U.S.A., revised to meet British conditions [31]. Here again there are now strong critics of the system of evaluating the labour efficiency by using this calculation of man-days available against those theoretically required. R. Dudman [17] has recently declared that this "useful concept had undergone a melancholy metamorphosis" and has acquired an unjustified degree of accuracy as a measure of efficiency in the use of farm labour.

The development of a satisfactory way of measuring the efficiency with which livestock convert grass and other feedingstuffs into a saleable produce has proved more difficult, and the existing methods for calculating the economic efficiency of the livestock enterprises vary widely in detail. There are, however, two main types of livestock efficiency standards: the first is concerned with the density of stocking, and the second with the output from the actual livestock carried, based either on the production per unit of livestock or on production in relation to the total amount of feedingstuffs available. Further work on the measurement of the efficiency of the livestock enterprises is still needed, for none of the existing indices is without its critics.

This procedure for analysing the economic organization of any farm became widely accepted when it was incorporated in the official handbook used in farm management advisory work [6]. The development of these manuals, and of accompanying work sheets, was the main task of farm management experts in the mid-1950s, and culminated in a study by O.E.E.C. on the preparation of national and regional handbooks in Europe [22]. The need for such has in fact provided a focal point for a very large proportion of the research work carried out in recent years into farm management in Britain, although much remains still to be done in this field.

DEVELOPMENT IN FARM PLANNING

The analysis of the faults in the organization of farms is, however, only the first part of the advisory workers' task. The development of a rational replanning of the farm has, until recently, been much more dependent on the subjective evaluation by the adviser of the alternative possibilities which the farmer might adopt. Some form of forward budgeting, either for the whole farm or for any part of it, was an integral part of the outlook of the progressive farmer long before it became a subject for academic discussion; nevertheless, the use of budgeting in advisory work has been of great value, particularly as the changes in emphasis of government price policy have given a considerable incentive to alterations in the organization of the individual farm. The principal problems involved in drawing up alternative farm budgets have been discussed at some length [30], but the examples given in the literature have rarely had much significance except on the farms for which they were specifically designed.

These difficulties have been met, at least in part, by the development of the concept of the gross profit earned by individual enterprises which goes towards meeting the overhead or joint costs not directly attributable to the enterprises themselves. This field of study has been most fully explored in Northern Ireland, where the surveys carried out are designed to show the gross profits earned by the separate enterprises. It has been claimed that "if a sufficient stock of examples of gross profits were accumulated, with the relevant physical data, the task of budgeting would be greatly simplified. Advisers should in fact be equipped with ready-made up-to-date estimates for all the important enterprises, sub-divided as appropriate by method, kind of land, manurial treatment, variety, etc." [23]. Certainly, from the point of view of the farm adviser, such a system has great advantages both in its simplicity and in the ease with which up-to-date information can be incorporated. Nevertheless, it leaves much to the personal evaluation of the adviser; and, while it can be used to demonstrate the opportunities that exist for higher profits on the farms run with average ability, it does not ensure that the most profitable of all the possible policies will be the one adopted.

Mathematical Programming Techniques

This difficulty of overcoming personal bias in producing budgets in farm planning has been partly met by the development of a complex mathematical technique for determining the combination of farm resources—labour, land, machinery, buildings, etc.—that will give the maximum profit. This technique of linear programming, originally designed to solve the problem of allocating scarce resources in the war economy, has a wide range of application to farming problems as well. It is of considerable value within individual enterprises—as in determining the most economic ration to be fed to pigs, given the prices of constituents and the limits of the feeding of any of them [24]. Of greater importance is its use in finding the most profitable policy for a farm, given the range of opportunities that the farmer has before him [11]. Unfortunately, the technique is of limited usefulness to the farm adviser because of the complicated arithmetic it involves; but it has been employed to a considerable extent in research work in America, and now has its own lengthy textbook [16].

A simplified version of linear programming, generally called programme planning, is claimed to give answers that are only slightly less accurate, with no more than "an ability to perform simple arithmetic" [15]. Yet the amount of arithmetic required is still considerable, and this "poor man's approach" is open to criticism on the grounds that it throws out the baby with the bathwater. Simplification to the point at which it can be of general use in farm planning has yet to be achieved, and so far programme planning has not been adopted on any scale as a method of solving the practical problems involved in the reorganization of the farm business.

Nevertheless, much work is now being put into the further development of programme planning, and this seems to be the most promising of the current developments. The variability of conditions, both climatic and economic, under which agricultural production takes place makes precise programming extremely difficult; the optimum degree of precision required is one of the problems that urgently requires a solution.

Problems of Inadequate Technical Data

One of the major difficulties that linear programming by its very nature cannot overcome arises because the output of any product, or of a whole farm, is not strictly related to the input of factors in a linear fashion. Even though the law of diminishing returns is one of the first economic laws taught to a student, and the illustrations of it in the standard textbooks of general economic theory are almost entirely agricultural, many of the assumptions in farm budgeting in linear and programme planning, as well as in farm management handbooks, do not allow for the curvilinearity that is involved in farm production. For example, it is only recently that there has been any real qualification of the advice to the dairy farm concerning the "4 lb. to the gallon" rule in feeding concentrates, though two investigations made nearly 20 years ago [21, 33] showed most clearly that the relationship between the food consumed by a dairy cow and the milk produced was not linear. Farm economists and animal nutritionists are now trying to derive much more accurate feed input/milk output relationships, in order that the most profitable feeding levels for dairy cows may be much more closely defined [13, 20]. The problem of differentiating between cows of a varying inherent milking potential, after the differences in breeds have been allowed for, has so far made it very difficult to produce a simple guide to the correct amounts of concentrates which should be fed.

Fertilizers are the only other major factor of production for which anything like enough information is available on the outputs associated with the various levels of intensity of their use on soils of different types, and that refers only to a few crops. Indeed, this is a good illustration of the difficulties of getting adequate data for farm business planning even for a simple production factor, in spite of all the work that has been done on the response to fertilizers in this country and abroad.

This lack of information on the rates of return on additions to the level of resources used on the farm, particularly in feeding of livestock other than dairy cows, is undoubtedly the most serious gap in the data necessary for the rational planning of farm enterprises. Moreover, it seems likely that, when the relevant information does become available, its translation into farming practice will produce difficulties far greater than those faced by the advisory service up to the present time.

Labour and Capital Studies

The results of varying the more general factors of production, such as labour and capital, also require further investigation. The constantly decreasing size of the agricultural labour force has focused attention on the opportunities that exist for saving labour and for increasing efficiency by applying work study methods in farm production. Here again the lead in this field was taken by America, but Britain is probably further ahead than most of her European neighbours in the use of these techniques to reduce labour costs. The wide range of actual case-studies that have been made, notably by the I.C.I. work study unit, of the savings to be achieved from the reorganization of labour routines in farming and horticultural enterprises has shown quite clearly the potentialities of these techniques.

On the problems of increasing the return on capital, and of using the limited capital available to a farmer in the best possible fashion, little work has been done. Studies of machinery use, involving the farm as a whole and separate aspects of the farming programme, have been made; but they have generally been concerned simply with the economics of mechanization, rather than with the optimum use of the available capital. Nevertheless, they have thrown considerable light on the minimum acreages at which investment in particular pieces of equipment, such as combine harvesters, becomes justified [26]. It has, however, been impossible to allow for all the conditions met on commercial farms, and these studies are useful only as general guides to the purchase of new items of machinery.

MANAGEMENT PROBLEMS AND THE FUTURE

The value of the work done in this country on farm management can be seen most clearly on the Small Farm Scheme introduced in Britain in 1959 [8]. The two basic features of this scheme—the use of man-days as the criterion by which a farm may qualify for the grants, and the payment of these grants on condition that a reasonable budget is produced and followed—have both been introduced from the field of farm management. Moreover, the small farmer's problem is essentially an economic one, and the discussions on improving his position have inevitably been concerned primarily with managerial factors. The opportunities for the farmer of under 50 acres to produce an adequate income depend, more than they do on the larger farms, on his level of output. Investigations into the results from small livestock farms (which account for 80% of the total of small farms) have shown that the limits of economic expansion are rarely, if ever, exceeded in practice [9, 10]. Even holdings of the 30–40 acre group with outputs of over £200 an acre appear to be below the point at which the cost of the marginal unit of output is equal to the return from it, and therefore seem still to have the opportunity of increasing profits by expanding output.

The question of the most profitable level of output for a farm of any given size and type is one that requires considerable statistical ingenuity to answer, as can be seen in a study made by Jawetz of the dairy farms of Wales and the West of England [19]. The rapid fall of the most profitable level with rising acreage on these farms, from over £100 for the farms between 20 and 50 acres to £48 for the farms over 200 acres, is a reflection of the way in which managerial problems multiply as total farm size increases.

There has been, in recent years, a move towards simplifying the traditional mixed pattern of

British farming, in an effort to reduce the difficulties of managing farming units which are becoming increasingly complex. Greater specialization has led, in some cases, to a reorganization not only of the farm production programme, but of the marketing arrangements. In this way the management of the farm business has been spread over a larger total output, without incurring the same degree of diminishing returns to management as that generally found on the more typical farm. Certainly, there are signs that the pattern of farms in Britain will include a growing number of units concentrating on only two or three enterprises, but running each of them at a relatively intensive level.

The last decade has, however, seen only the beginning of a full analysis of the efficiency with which farms in Britain are managed. Even when all the information on input/output is assembled, and statistically valid samples of farm costs and returns have been collected and analysed according to the most advanced econometric methods, the problem of the differences in the inherent managerial capabilities of the farming population will remain. We still know far too little about the way in which these capabilities can be developed to the full, or about the way in which they can be supplemented by advice and help from outside the farm itself. The fascination of working on farm management problems, and the difficulties of producing perfect answers to them, will remain, however much work is done. Of all the factors that cause variation in the actual results achieved on any sample of farms, the quality of the farmer as a manager of the land, labour and capital at his disposal is undoubtedly the most important—and the hardest to analyse.

REFERENCES

[1] Anon. (1943). *Agricultural Research in Great Britain.* H.M.S.O., London.

[2] Anon. (1949). *Management in Farming.* H.M.S.O., London.

[3] Anon. (1952). *Agricultural Economics at Cambridge*, 1896–1915. School Agric., Cambridge.

[4] Anon. (1954). *Annual Review and Determination of Guarantees.* H.M.S.O., London, p. 3.

[5] Anon. (1954). *Costs and Efficiency in Pig Production.* Min. Agric. Fish. H.M.S.O., London.

[6] Anon. (1954). *The Farm as a Business—A Handbook of Standards and Statistics for use in Farm Management Advisory Work.* H.M.S.O., London.

[7] Anon. (1955). *Farm Planning and Budgeting Services in Farm Management Advisory Work.* O.E.E.C.

[8] Anon. (1958). *Assistance for Small Farmers.* Cmnd. 353. H.M.S.O., London.

[9] Attwood, E. A. (1957). *Agric. Rev.*, **3**, (6), p. 3.

[10] Attwood, E. A. (1959). *The Problem of the Small Livestock Farm.* Dep. Agric. Econ., Univ. Coll. Wales, Aberystwyth.

[11] Barnard, C. S. and Smith, J. V. (1959). *Resource Allocation on an East Anglian Farm.* School Agric., Cambridge.

[12] Blagburn, C. H. (1951). *Some Economic Aspects of Increasing Farm Output.* Dep. Agric. Econ., Univ. Reading.

[13] Blaxter, K. A. (1959). *Scientific Principles of Feeding Farm Livestock*, pp. 39–42. Farmer and Stockbreeder Publications, London.

[14] Carslaw, R. McG. (1931). *Farm Management Research Technique.* Coll. Estate Management, London.

[15] Clarke, G. B. and Simpson, I. G. (1959). *J. Agric. Econ.*, **13**, (3), 250.

[16] Dorfman, R., Samuelson, P. A. and Solow, R. M. (1958). *Linear Programming and Economic Analysis.* McGraw-Hill, New York.

[17] Dudman, R. (1960). *Digest Agric. Econ. No.* 11. Agric. Econ. Res. Inst., Oxford.

[18] Heath, W. E. (1952). *J. Agric. Econ.*, **10**, (1), 60–8.

[19] Jawetz, M. B. (1957). *Farm Size. Farming Intensity and the Input/Output Relationships of some Welsh and West of England Dairy Farms.* Dep. Agric. Econ., Univ. Coll. Wales, Aberystwyth.

[20] Jawetz, M. B. (1959). *Theoretical and Economic Rules of Feeding Concentrates to Good Friesian Cows at Various Levels of Daily Yield.* Dep. Agric. Econ., Univ. Coll. Wales, Aberystwyth.

[21] Jensen and Woodward (1942). *Tech. Bull. U.S. Dep. Agric.*, No. 815.

[22] Jones, A. and Burlingame, D. B. (1958). *Farm Management.* O.E.E.C.

[23] Liversedge, V. (1956). *J. Agric. Econ.*, **11**, (4), 415.

[24] Mackenzie, H. C. and Godsell, T. E. (1956). *J. Agric. Econ.*, **11**, (4), 457.

[25] Napolitan, L. (1953). *J. Agric. Econ.*, **10**, (3), 205–17.

[26] Nix, J. S. and Attwood, E. A. (1954). *Power Farmer*, **13**, 214.

[27] Orwin, C. S. (1938). *Agricultural Economy* 1913–38. 25th Rep. Agric. Econ. Res. Inst., Oxford, p. 20.

[28] Rasmussen, K. (1953). *J. Agric. Econ.*, **10**, (3), 226.

[29] Roberts, I. P. (1903). *The Farmers' Business Handbook.* Macmillan Co., New York.

[30] Sturrock, F. G., Wallace, D. B. and Godsell, T. E. (1954). *Planning a Farm for Higher Productivity.* School Agric., Cambridge.

[31] Sturrock. F. G. (1950). *J. Agric. Econ.*, **9**, (1).

[32] Wright, Karl T. (1952). *J. Agric. Econ.*, **10**, (1), 17.

[33] Yates, F. A., Boyd, D. A. and Petit, G. H. (1942). *J. Agric. Soc.*, **32**, 428.

THE CONSERVATION OF SOIL FERTILITY IN TROPICAL PLANTATIONS

T. Eden

(*Formerly Director of the Tea Research Institute of East Africa, Kericho, Kenya*)

In plantation cropping in the tropics much use has been made of shade trees and cover crops in the hope of mitigating some of the harsher effects of the climate on crop and soil. Recently, however, it has been suggested that these practices can be dispensed with so long as manuring is liberal, and the issue will not be settled until long-term work expands our knowledge of the factors involved in this complex ecological problem.

In tropical climates the hazards of soil deterioration are so great and widespread that agriculture has for the most part remained extensive and the conservation of soil fertility is a fundamental problem. This contrasts sharply with agriculture in temperate regions, where systems have been evolved under which crops can be cultivated continuously and produce high yields without ill effects on the soil; indeed, with the increased application of scientific knowledge, fertility has been enhanced.

This trend in temperate countries has been related by Jacks [12, 13] to the emergence of urban and industrial communities whose comparative affluence enables them to pay high prices for agricultural produce, so that the wealth of the town can support the cost of progress and improvement in the agricultural sector of the national economy. In the tropics, however, these conditions do not obtain except in plantation agriculture, particularly that devoted to perennial crops. Such crops fetch reasonably high prices in world markets if they are not subject to overproduction, and have thus been able to pay for research into intensive methods which have, on the whole, been widely accepted. The growing number of commodity research stations, supplementary to those of a general nature maintained by governments, provides evidence of the intensive nature of plantation agriculture. Nothing is more striking in the tropics than the sight of flourishing estate agriculture side by side with poverty-stricken peasant farms growing subsistence crops.

The reasons for this contrast are in part accidental and stem from the nature of plantation crops rather than from a conscious effort to safeguard fertility. Their perennial habit gives them an initial advantage. Tea, coffee, cocoa, sugarcane and sisal, to quote examples, are planted closely enough for their permanent root systems and their foliage to mitigate the worst ravages of tropical rainfall and soil erosion. It would be idle to deny that despite these favourable circumstances there has, in times past, been thoughtless exploitation of soil resources in plantation cropping; but the dangers of monocultural systems gradually came to be realized and interplanting with leguminous species began to make headway, originally in the form of trees, and later as cover crops and bush green manures.

Many of the species used were controlled by pollarding and lopping; others were left untouched so as to form a higher canopy. Where leguminous species did not thrive, non-leguminous types were introduced. The use of trees, cover crops and mulches provided a three-tier system of soil and crop protection. Because these three types of soil protection are not easily standardized, experimental work is made more complex than with straightforward manuring or physical cultivation, and its interpretation is often difficult.

This short article reviews some of the agricultural implications involved and comments on the information so far available with special relevance to the question, now frequently raised, as to whether these systems are largely unnecessary. Plantation agriculture has an air of stability in the tropics that is absent elsewhere. To what extent are shade trees, cover crops and mulches determining factors in the maintenance of this stability?

SHADE TREES

Potential Benefits

The interplanting of tea, coffee and cocoa with other tree species was not conceived as a method of soil amelioration. The natural habitat of these crops is forest, of which they were in the first place a component. Although, as will be considered in some detail later, trees grown in conjunction with a crop have a complex ecological effect, the original motive in planting them was to simulate natural conditions as regards shade, and throughout the history of their varied use the term shade tree has been dominant.

Reduction of light intensity, temperature and air movement establishes a more equable eco-climate, thus minimizing scorch on leaf and branch, which can be serious enough in the early stages of establishment to bring about total loss of the plant [15]. The contribution that interplanted trees make to occluded precipitation is considerable in extreme climates; in Russell's estimation [24], this occluded precipitation is as valuable as its equivalent in normal rain. Heavy tropical storms, in Africa particularly, are often accompanied by hail which severely damages both foliage and branches, to the detriment of subsequent development. Some indication of the extent of potential damage is given by the fact that tea, in which the crop is a portion of the foliage, can be put out of production for as much as two months. Shade reduces this damage and moderates that from high wind. Even without inflicting physical injury, wind is a potent inhibitor of growth.

Shade is as beneficial to the soil as to the plant. High temperatures and heavy rainfall leave many tropical soils woefully depleted in organic matter, with concomitant effects on their physical and chemical condition; shade trees, by moderating the impact of rain on soil and by providing protective mulch that accumulates most prolifically in the wet season, contribute to soil conservation. The mulch can be quite copious. A normal stand of *Grevillea robusta* on an experimental site at the Tea Research Institute of East Africa deposited 6·5 tons of leaf per acre in a year, calculated in terms of dry matter—an equivalent of about 50 tons of the crude material [6]. Other beneficial effects of this mulch will be considered later.

Some of the presumed effects of shade trees are not so clearly defined. There is the important question of depletion of water reserves. Pereira [21] investigated this subject on a commercial tea estate by sampling to the depth of 15 ft. He found no striking difference between the root range of tea and associated *Grevillea* on the red earths of the western escarpment of the Rift Valley in Kenya. This is not paralleled on the tea soils of Ceylon, which are derived *in situ* from gneiss. But it is all the more interesting that the presence of shade trees on a deep and highly permeable soil reduced the soil moisture (as inches depth of water) in 15 ft. profiles by only 1½%. As a matter of practical observation it does not appear that, bearing in mind the modification of the eco-climate, dispersed shade has detrimental effects on the crop's water use, though concentrated tree cover, as for instance wind belts, can be very harmful. The part played by shade trees in the circulation of nutrients is largely unexplored territory; in particular, their function in the regulation of minor elements available to the crop needs precise definition.

Many of the difficulties in investigating and interpreting shade tree effects stem from the fact that, with dispersed shade, it is virtually impossible to define in quantitative terms the intensity and range of individual characteristics, such as light intensity, canopy cover, root competition, and soil modification in relation to crop yield, which is an integrated effect. Over any area of land that has an agricultural, as apart from a formal experimental significance, none of these factors is uniform or standardized.

It is obvious that shade trees must be controlled and removed before their size becomes more of an encumbrance than an asset. The efficient management of shade demands a rotational scheme of planting and eradication, so that a moderate and efficient cover can be maintained. The choice of species depends on a number of considerations. Many leguminous trees have an umbrella-like canopy with feathery foliage casting a light and dappled shade. Their symbiotic habit is an added recommendation, though how much additional nitrogen they contribute is not known with any exactness. The climatic range in which they thrive has a limiting effect on their employment, and consequently their use, though favoured, is not ubiquitous.

Conflicting Factors

In spite of the real and presumed advantages of shade trees in protecting soil and conserving fertility in that part of the profile on which the crop's root system mainly depends, there has recently developed a climate of opinion that is adverse to their use. In tea, coffee and cocoa plantations it has proved possible to maintain high production without shade, provided that copious manuring is carried out. The removal of shade almost invariably gives an immediate crop increase on manured tea fields, but one that is not always permanently maintained. Cocoa may suffer a setback due to defoliation but later shows similar increases in crop and manurial response. Manurial experiments conducted on shaded sites frequently show a low or a null response to fertilizers [3, 7, 17].

The task of disentangling the various factors that are operative when shade is established or removed is a formidable one. Quantitative estimates of what is happening to the crop, the shade and the soil medium are in the nature of things intermittent. In a continually changing ecological situation only extensive and long-term trials promise any measure of assured validity. Such a project, on tea, is in its initial stages on a commercial estate, under the direction of the East African Agricultural and Forestry Research Organization in association with the Tea Research Institute of East Africa and Messrs. Brooke Bond (E. Africa) Ltd.

Investigation of the shade problem in relation to crop yields has been carried out for a number of years on tea by Wight [26] and on cocoa by Murray [20]. Wight's work has clearly shown the complexities of the problem. He was concerned with the shade effect of *Albizzia chinensis*. Cautiously avoiding generalization in respect of other crops or other forms of tree shade, he uncovered facts which should, on the one hand, stimulate intensive work and, on the other, engender caution in writing off the benefits of shade as revealed by short-time studies.

Wight based his findings on tea grown with and without fertilizers under three conditions of light: (*a*) with full insolation; (*b*) with artificial shade provided by screens; (*c*) with shade trees of *Albizzia chinensis*. His main conclusions were as follows. On mature tea, artificial shade intercepting 55 per cent of direct insolation progressively increased the yield of tea, over six years, from 57 to 78 per cent in comparison with unshaded tea. When tree shade was used the ascending order of yields was: (1) Control (no shade; no nitrogen); (2) Nitrogen at 84 lb. per acre; (3) *Albizzia* shade; (4) *Albizzia* shade plus 84 lb. nitrogen. The response to nitrogen was diminished by shade. Tea shaded with screens and manured was less productive than that shaded by *Albizzia* receiving equivalent nitrogen. He concludes that though shade *qua* shade is the major factor, there are other effects also. These are not confined to the problematical addition of symbiotic nitrogen to the soil and plant, but affect the phosphate economy and possibly that of other elements, notably calcium.

Conflicting opinion under conditions prevalent in commercial plantations is attributed by Wight to the fact that shade is patchy, so that in some areas the typical fertilizer responses are operative while in others the shade tree effect is dominant. In general, the conclusions drawn are that high yields can be secured and maintained by either shade trees or manures but not equally by the employment of both at once: "There is a density of shade giving a certain increase in yield of the bush surface that cannot be bettered by using ammonium sulphate under shade: but lesser shade would give lesser yield that could be increased by sulphate of ammonia. The biggest return per pound of ammonium sulphate, however, would be got by using large doses in full sun, but should fertilizer be discontinued yield would drop to a lower level than that obtained under shade alone."

Many questions need further elucidation. How far are these complex soil-plant relationships applicable to crops other than tea? If symbiotic nitrogen is not the chief nutritional factor so far as *Albizzia* shade is concerned, to what extent are these effects reproduced with other commonly used non-leguminous trees, e.g. *Grevillea?* Wight concerns himself with the contemporaneous association of crop and shade tree, but it is not clear from his results for how long an *Albizzia* type of effect would persist as a residual component of soil conditions after the trees were removed.

There thus seems to be some evidence that the nutritional economy of tea grown under shade is different from that under full insolation. Similar indications are given in Murray's work on cocoa [20]. When cocoa has developed sufficiently to provide its own characteristically heavy shade canopy, Murray holds that phosphate nutrition becomes more important than that of nitrogen. How far these changes in nutrient response are ascribable to parallel changes in crop metabolism on the one hand or to changes in soil condition on the other is a further point that needs elucidation.

COVER CROPS

Some of the effects of permanently established shade trees can be provided by the use of cover crops without the complication of shading on the crop: protection from soil erosion, suppression of weeds and, to a lesser extent, modification of the eco-climate are the chief examples. Several factors, however, have militated against the general acceptance of cover crops except in special circumstances.

It is often difficult to establish an effective cover, especially on slopes where protection is most needed. Weeds can often compete very successfully with the seedlings of a cover crop, even if it has been inoculated with an appropriate strain of

Contour-planted tea well established under high and medium shade (*Grevillea* and *Albizzia*). St. Coombs, Ceylon. (Photograph by courtesy of Dr. Brian Webster.)

Rhizobium. On most plantations there are tracts of land where cover crops will not grow vigorously. There has also been considerable resistance to the use of cover crops because in the plantation industries the clean-weeding tradition dies hard. This tradition is in part a carry-over of notions more generally applicable to annual crops in a temperate climate, and is all the more understandable because weeds are a far greater menace under the forcing conditions that characterize the tropics.

Whether weeds or cover crops are in question, perennial plants are in a much better position to cope with competition than annuals that have to pass through the vulnerable seedling stage every year; though this period is also a delicate one for perennials, and the adverse factors of unpredictable climate and soil erosion are particularly severe at this time. Attempts to establish a cover frequently meet with failure, and when the planter does succeed he may find difficulty in controlling weeds that could easily smother the young crop if they got out of hand. In addition, cover crops are seldom a complete deterrent of weeds, particularly of grasses of stoloniferous habits, and the enhanced cost of eradicating these when interspersed with a cover crop goes far to tip the balance against cover crops in the eyes of a planter of ingrained clean-weeding habits.

Natural Cover

Any consideration of ground cover must logically start with that of weeds. Practical experience shows that for the smaller perennial crops, notably tea and coffee, grass species such as *Digitaria scalarum*, *Imperata cylindrica* and *Panicum repens* are so markedly competitive as to be wholly unsuitable. On the other hand, broad-leaved herbaceous dicotyledons are considerably less harmful except in the early stages of crop establishment. Once the crop is well developed, the shade it provides has a controlling influence on weed growth.

An experiment at the Tea Research Institute of Ceylon [4], which investigated weed and associated cultivation effects, revealed a surprisingly small adverse effect from soft-weed competition—less than 9 per cent loss of crop over a period of three years. Whether the competitive effect was due to distraint on water or nutrient there was no means of judging, although the drain on nutrients by a rapidly growing weed cover is significant. In a supplementary experiment [5] the loss of nutrients, inherent in clean weeding and the destruction of weeds off the land, amounted in pounds per acre to the following quantities: nitrogen 11, phosphoric acid 5, potash 21.

The practice of clean weeding alters the ecological balance of the weed flora and may result in the dominance of a quickly growing species that is beneficial rather than harmful. *Oxalis latifolia*, a bulbous herb, dies down in dry weather but regenerates at the onset of the rains and proliferates so rapidly that it cannot be eradicated by weeding. Its soil-conserving properties have been commended in official publications in Ceylon [2, 10]. *Polygonum nepalense* is another species that is harmless and has a short life cycle. Prolific seeding favours its frequent dominance, and its liability to attack by the rust fungus *Puccinia polygoni-amphibii* provides an adequate check on over-luxuriance [5]. Broadly speaking, however, weeds as a cover in tea and coffee are tolerated only when they cannot be controlled.

The case of rubber is quite different. About twenty-five years ago a method of rubber cultivation characterized as the "forestry" system began to be talked about. It was based on the assumption that since *Hevea brasiliensis* was a forest tree its "natural" growth under forestry conditions, i.e. without weed eradication, would be beneficial. This view, in common with all advocacy of "natural" methods of crop cultivation, disregarded the fundamental facts that all agriculture is a departure from closed systems of natural growth, and that the object of cultivation is an enhanced economic return. Nevertheless the basic idea was capable of rational development. It focused attention on the ecology of rubber-growing and led to an investigation at the Rubber Research Institute of Malaya, the results of which were collated by Haines [11].

The outcome was a system of conscious control of the natural plant associations without wholesale eradication of the low-growing vegetation. Certain species which were useful as initial colonizers of newly opened land became harmful if allowed to develop into climax associations. Representatives of this class were tufted grasses, *Imperata cylindrica* (lalang), ferns and bracken, particularly *Gleichenia sp.*, and woody species such as the Malayan rhododendron, *Melastoma*. These were removed. After an initial setback in growth of the rubber, a satisfactory ecological balance could be achieved by slashing at intervals, and if this was done every six months less eradication was necessary. In the warm, humid climate reduction of the debris to an organic mulch was rapidly accomplished by fungi and termites. The cost was less burdensome than clean weeding, no harmful check on the rubber was experienced, and there was an undoubted improvement in soil stability and condition. The system had a wide application, even though it was not universally approved. In more recent times the labour costs involved have added complications, and the present tendency is toward achieving a somewhat similar goal by the use of various weedkillers and arboricides [27].

Leguminous Cover Crops

A more distinctly agricultural method of soil fertility protection is the use of leguminous cover crops. These have a putative advantage of fulfilling, after a fashion, the function of recuperative leys in systems of alternate husbandry. In rubber and tea three species particularly have been tried—*Pueraria phaseoloides*, *Dolichis hoseii* and *Centrosema pubescens*—but they soon proved a failure on tea because they climbed through the bushes and complicated plucking operations. Their place has been taken by leguminous bush crops, such as species of *Tephrosia* and *Crotalaria*, which provide some protection for the soil though their chief use is as green manures.

In rubber a valuable cover can be grown so long as the rubber tree canopy does not cast too deep a shade, but eventually a stage is reached when the cover deteriorates and is invaded by other species more tolerant to shade. Leguminous covers are at their maximum vigour in the first three years. Their establishment and growth are helped by applications of phosphatic fertilizers which facilitate the invasion of roots by the mobile phase of *Rhizobium*.

Centrosema has been shown *in vitro* to be active in the fixation of nitrogen in Malayan soils, and soils colonized by it have a higher ammonia content than those from which it is absent. Some soils seem to favour *Centrosema* and others *Pueraria:* the former establishes itself better on land where natural vegetation has been burned at the time of clearing [25]. Whether the transitory nature of effective cover is due entirely to shade conditions or to positive sickness akin to clover sickness is not known.

The beneficial effects of cover crops are most needed in young plantations and periodically in mature plantations when the soil surface is exposed by pruning operations. The eco-climate in the vicinity of the cover crop is modified, soil temperature is lowered, air temperature for some distance above the surface of the cover crop is increased, and so too is the relative humidity. Generally this alteration would be regarded as beneficial, but not where widespread fungus disease is troublesome, e.g. blister blight in tea [15].

The use of cover crops meets with difficulties in climates having a markedly seasonal rainfall. The presence of cover when the rains start, often with devastating severity on soil in a poor state of receptivity, is highly desirable but cannot easily be ensured without endangering the major crop during the dry weather.

In Nyasaland [16] soil moisture determinations using gypsum blocks showed that there was an absolute moisture deficiency in the dry weather on tea grown without cover, and that a cover crop of *Stylosanthes gracilis* accentuated an already dangerous situation. To avoid complications the tea was pruned at the start of the experiment, so the noted effects were due to the cover crop almost entirely. Under the cover the drying out of the soil started two months earlier than on bare land, and the moisture content fell below wilting point for 4½ months in the top soil and for 4 months at a depth of 4 ft. Without the cover the surface layers were at wilting point for three months only and for two at the lower depth. The damage to the main crop in actual deaths and delayed recovery of the bushes was plainly visible.

MULCH

Common to shade trees and ground cover is the litter that accumulates from their shed leaves. How persistent this may be depends on the nature of the material and the biological agencies at work on it: soft leaves decompose rapidly in accordance with their low carbon-nitrogen ratio; lignified tissues and material like graminaceous straw having hard glazed surfaces decompose more slowly. Termites rapidly disintegrate litter but concomitantly produce a surface soil of good structure.

The difficulties encountered in the establishment and control of shade trees and cover crops make the use of mulch a simpler way of securing many of their beneficial effects. The parallelism is only partial. Whereas shade trees and cover crops operate in a closed economy, mulching involves a transference of fertility which is not always desirable. The very full collation of experimental work on mulches published by the Commonwealth Bureau of Soil Science [14] reveals many contradictions in assessment of their usefulness, and in practice failures and disappointments are often the result of mismanagement. It is nevertheless clear that, when properly used, mulches have important advantages. They are easily regulated and they can be used with optimum effect at the most critical time, though this flexibility carries with it the need for good management. They also have a positive contribution to make in suppressing weeds, diminishing soil temperatures and evaporation, and protecting against soil erosion and loss of structure in surface soils.

The effect of mulches in the conservation of moisture supplies is by no means restricted to the prevention of evaporation and run-off. In heavy storms their absorptive capacity for rain has a buffering effect in regulating the speed of absorption by the soil itself. A number of investigations have shown that, when a mulch is saturated, percolation through the soil is maintained and even enhanced by the protective litter, and that drains function more efficiently on mulched than on unmulched land. The reasonable inference from the classic work of Lowdermilk [18, 19] and his successors is that, where mulch is present, the soil pores are not choked with the fine fractions of soil which would otherwise form an impermeable layer and so determine the rate of percolation whatever the condition of the deeper layers may be. Mulch lessens the compaction of soils that are not highly water-stable.

This phenomenon of water acceptance by mulched soils is, according to Pereira and Jones [22], the main benefit contributed by mulching, and its practical importance was confirmed by increases in yield of coffee obtained when the mulch was applied before the rainy season. This work also stresses the importance of good management. Too thick a mulch can prevent a soil from benefiting from light precipitation, because all the rain may be immobilized and re-evaporated before any portion of it reaches the soil.

The effects of mulch on chemical reactions in the soil have only recently been seen to involve complications, some harmful, some beneficial. Mulch sometimes depresses the nitrate content of the surface soil [8, 9]; but because the same effect is produced by shade, the mode of action is not clear.

A more tangible effect is that of creating a state of nutrient unbalance in the soil. Some of the plant materials used, notably *Pennisetum purpureum*, are rich in potash (6 per cent in the dry matter), and if these are applied as a mulch at the rate of 10–15 tons per acre a large amount of this potash will be released into soils which may be only moderately supplied with other essential nutrients. Since excessive potash diminishes the available magnesium in the soil, this may induce a state of deficiency harmful to specific crops; coffee is highly susceptible, and tea also may be affected [1, 23].

Mulch apparently affects favourably the phosphate economy of soils [7, 26], and where there is a high manganese content it protects manganese-sensitive crops from damage.

As a special treatment mulching is a valuable practice as long as it can be carried out economically, but on a large scale it is generally expensive unless the material is naturally produced by shade trees or cover crops, or is a waste product like bagasse or sisal pulp that is easily available and has in any event to be collected and disposed of. Such material is not distraining on the fertility of extraneous areas.

CONCLUSION

The essence of investigations into the effects of shade trees and cover crops as living components of the soil-crop complex lies not in the individual factors that are modified but in the integrated ecological situation that they create. It would be premature to conclude from experiments of limited duration that they can profitably be dispensed with so long as more liberal manuring is practised. The project of the East African Agriculture and Forestry Research Organization brings the hope that the very detailed assessment of the factors at work and the co-operative labours of specialists in the fields of soil physics, chemistry, hydrology, plant physiology and ecology, all concentrated on a specific site viewed as an ecological whole, will provide a new insight into the problem of maintaining soil fertility and high crop production under tropical conditions.

REFERENCES

[1] Anon. (1951). *Sessional Paper No.* 3. Committee on Soil Erosion (Ceylon).

[2] Chenery, E. M. and Shoenmaekers, J. (1959). *E. Afr. J.*, **25,** 25.

[3] Cunningham, R. K. and Lamb, J. (1959). *J. hort. Sci.*, **34,** 14.

[4] Eden, T. (1949). *Monographs on Tea Production in Ceylon*, No. 1, 36. Tea Research Institute of Ceylon.

[5] Eden, T. and Bond, T. E. T. (1945). *Emp. J. exp. Agric.*, **13,** 141.

[6] Goodchild, N. A. and Foster-Barham, C. B. (1957). *Rep. Tea Res. Inst. E. Afr.*, **17.**

[7] Goodchild, N. A. and Foster-Barham, C. B. (1958). *Rep. Tea Res. Inst. E. Afr.*, **18.**

[8] Griffith, G. Ap and Manning, H. L. (1949). *Trop. Agric.*, **26,** 108.

[9] Griffith, G. Ap and Mills, W. R. (1952). *Recent Investigations*, p. 23. Department of Agriculture, Uganda.

[10] Haigh, J. C. *et al.* (1951). *A Manual on the Weeds of the Major Crops of Ceylon.* Department of Agriculture, Ceylon.

[11] Haines, W. B. (1940). *Planting Manual No.* 6 (2nd edit.). Rubber Research Institute, Malaya.

[12] Jacks, G. V. (1956). Presidential Address to Brit. Assoc., Sect. M.

[13] Jacks, G. V. (1960). *New Scientist*, **8,** 467.

[14] Jacks, G. V., Brind, W. D. and Smith, R. (1955). *Tech. Comm. Commonw. Bur. Soil Sci., No.* 49.

[15] Kirkpatrick, T. W. (1935). *The Climate and Eco-climates of Coffee Plantations.* East African Agricultural Research Station, Amani.

[16] Laycock, D. H. (1958). *Rep. Tea Res. Sta. Dep. Agric., Nyasald.*

[17] Laycock, D. H. (1959). *Rep. Tea Res. Sta. Dep. Agric., Nyasald.*, **17.**

[18] Lowdermilk, W. C. (1930). *J. Forestry*, **28,** 474.

[19] Lowdermilk, W. C. (1931). *Agric. Engng*, **12,** 107.

[20] Murray, D. B. (1952, 1953, 1954). *Report on Cacao Research.*

[21] Pereira, H. C. (1959). *Quart. Cir. Tea Res. Inst. E. Afr.*

[22] Pereira, H. C. and Jones, P. A. (1954). *Emp. J. exp. Agric.*, **22,** 23.

[23] Robinson, J. B. D. and Chenery, E. M. (1958). *Emp. J. exp. Agric.*, **26,** 259.

[24] Russell, E. J. and Russell, E. W. (1950). *Soil Conditions and Plant Growth* (8th edit.). Longmans, London.

[25] Watson, G. A. (1957). *J. Rubber Res. Inst. Malaya*, **15,** 2 and 168.

[26] Wight, W. (1958). *Rep. Tocklai Exp. Sta.*, 75.

[27] Wycherley, P. R. (1960). *J. Rubber Res. Inst. Malaya*, **16,** 87.

POLLINATION OF FIELD BEANS

W. A. Scriven, B. A. Cooper and H. Allen

(National Agricultural Advisory Service and Warwickshire County Council)

Observations on bee behaviour and experiments by the authors show that, contrary to common belief, honey and wild bees are of great importance in pollinating field beans. Whether in a good year for bees and beans or a bad one, yields of cross-pollinated crops can be double those of self-pollinated crops. The decline in beekeeping accounts for the low yields now obtained; the remedy is to place hives near crops at flowering time.

For some years now controversy has centred around the bean crop, particularly winter beans, of which it has often been said that yields are not what they used to be. Yet the crop has found a place in British agriculture since Roman times and, though systems of farming have changed through the centuries, the field bean with its moderately high protein content has consistently been grown.

In 1886, when agricultural statistics were first available, some 450,000 acres of field beans were grown in Britain; but at the turn of the century, when supplies of cheap imported protein were plentiful, the acreage was near the 250,000 mark, and it fluctuated around this figure until 1923, after which it steadily fell to rather less than 140,000 acres in 1939. With the outbreak of World War II the nation once again became dependent on supplies of home-produced protein, and thus the bean crop was expanded to close on 300,000 acres in 1944. A sharp decline followed in spite of efforts to stimulate interest in the crop, and only some 80,000 acres are now grown.

How has this drop in acreage come about? Is the bean now harder to grow, are its pests and diseases more prevalent, or is there some other cause? To these questions there is no clear-cut answer, though available information indicates that the crop has lost its popularity because of the general decline in yields. It seems ironical that farmers, plant breeders and scientists should have to admit this while the yields of other farm crops have steadily risen.

Nevertheless efforts have been and are being made to improve the yield of field beans, and in recent years the problem has been approached from various angles: selection of stocks; introduction of new varieties; changes in cultivation, depth of sowing and spacing; manuring; inoculation to stimulate nodule development; spraying as an aid to flower setting; and development in pest and disease control. On the whole, such work has increased our knowledge of bean growing and some progress has been made, but the expected increase in yields has not materialized. This perhaps is not altogether surprising, since the one natural factor of importance has been overlooked. It is, simply, that the bean flower produces nectar and pollen for the attraction of insects, particularly bees, implying that bees do have a part to play in pollination and hence influence the production of seed.

Workers have tended to regard the bean as self-fertile and have accepted the oft-repeated statement that the bean plant is 60% self-pollinated. Acting on the assumption that insects are of little or no importance in bean production some workers have directed their efforts to the development of a completely self-fertile bean plant, only to find that the nearer they seem to approach their goal the less vigorous is the plant and the fewer are the flowers which set—a fact that explains the degeneration of bean stocks in areas where insect pollinators are scarce.

Meanwhile our investigational work on the pollination of clovers, brassicas and fruit had convinced us of the importance of bees and indicated that the honey bee might also have a vital role in bean pollination. In a survey of bean-growing areas in Lincolnshire we observed that honey and bumble bees were numerous in the good bean districts, whereas few were to be found in the districts where beans were regarded as a poor or unprofitable crop. Our first objective, therefore, was to ascertain if the introduction of honey bees into these low-yielding areas would influence bean production. This was done, and it was found that the presence of bees in the bean crop at flowering time led to better pollination and increased yields.

Following up these observations, we compared the effects of self pollination with cross pollination. This we did by enclosing plots of beans with nylon net to exclude bees from the crop at flowering time, at the same time promoting cross pollination in the open field with free-flying bees from hives placed near the crop. This straight comparison gave striking results: the self-pollinated plots yielded less than 15 cwt. per acre, whereas the cross-pollinated crop in the open yielded over 35 cwt. per acre.

Since this work had been based on surveys, observation and simple comparison, the next step was to lay down carefully controlled experiments. Before doing so, however, it was essential to find out whether honey bees would satisfactorily carry out pollination in a confined space. Earlier attempts to settle this problem had been made by placing a hive on the outside of a cage and, by means of a control slide, allowing the bees to fly abroad one day and directing them into the cage the next. Such alternating conditions caused a high mortality among the bees, for bees that have experienced flight in the open and become accustomed to flying abroad will not settle down to work in a confined space but keep striving to escape until they become exhausted and die.

To avoid such losses we adapted to our purpose a technique well known to beekeepers—the building of a nucleus alongside the parent stock. This allows the flying bees to return to the parent hive, leaving in the nucleus only the young bees that have not learned to fly; and it is these young bees which accommodate themselves to cage conditions and settle down to work and carry out the job of pollination in the confinement of a cage. A four-frame nucleus, well stocked with young bees, and with a laying queen, plenty of brood, ample pollen and some honey, was found to be ideal for enclosed pollination work, provided the bees were kept supplied with water and given a little syrup as required.

EXPERIMENTS IN 1956–57

With this experience of bee behaviour and a satisfactory method of ensuring cross pollination by caged bees, further progress became possible, and a field experiment was laid down in 1956–7.

Experimental Procedure

The trial comprised five experimental treatments as follows:

1. *Self Pollination.* Bean plots were caged to exclude bees, ensuring that the flowering plants therein could only be self pollinated and become self fertile.
2. *Cross Pollination.* Bean plots were caged, and a nucleus of bees was placed inside each cage at the onset of flowering (Figure 4) and kept there until the end of the flowering period, thus ensuring that all flower trusses would be pollinated by honey bees.
3. *Effects of Reduced Light on Pollination.* To provide a check on Treatments 1 and 2, and to ascertain the effect of shade and reduced light on pollination and pod set, cages were placed on bean plots but left open on the north side to give access to free-flying bees.
4. *Free Pollination on Control Plots.* These plots were the same size as the caged plots and staked at each corner, but they were entirely open and so were subject to free pollination and unaffected by shade or reduction of light.
5. *Free Pollination in the Open Field.* Hives at the rate of one to the acre were placed around the bean fields at the onset of flowering (Figure 3), ensuring that the whole field as well as the control plots would be freely pollinated.

Treatments 1–4 were randomized but sited in areas of like plant population. The cages were of the standard size and type used for experimental work, that is 9 ft. × 9 ft. × 6 ft. high, but covered with Tygan net, a material that readily admits light and air yet is impervious to pollinating insects.

The experiments were carried out with a named and approved variety of winter beans on bean soil and in bean districts. Cultivations were those generally adopted for the crop. As the land had previously been done well in the rotation, no manure was applied. Sowing was done in the latter part of October 1956, the seed being drilled at the rate of 14 stone/acre in rows 24 in. apart and 3 in. deep. Seed germination and plant establishment were good, and though some sharp frosts were experienced during the winter the plants were not adversely affected. Spring cultivations were restricted to inter-row cultivation, once-hoeing with a tractor-mounted steerage hoe.

In 1957 the cages for Treatments 1–3 were placed on the plots just before the onset of flowering in the third week in April (Figures 1 and 2).

Observations and Results

From the start of flowering to its end in mid-June there were no apparent differences between treatments either in the type of flowers or the number of flower trusses per plant. Observations, however, did show that the honey bee, contrary to accepted belief among beekeepers, *does* pierce the base of the flower to facilitate the gathering of nectar (Figure

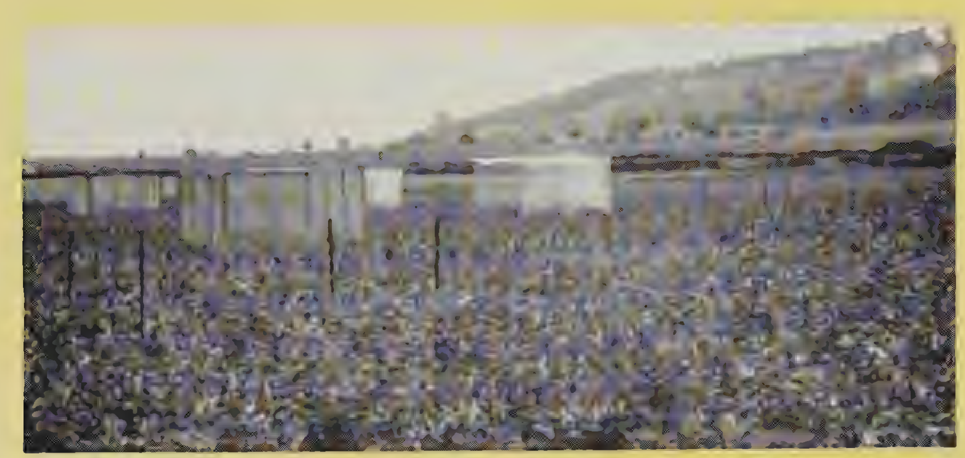

FIG. 1. Experimental site, showing caged plots and control plots marked by stakes.

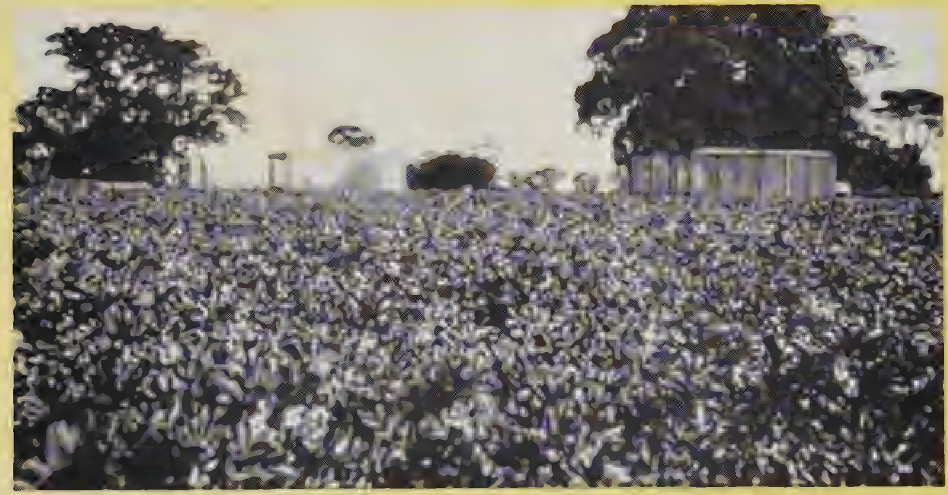

FIG. 2. Cages in a crop of winter beans in full flower.

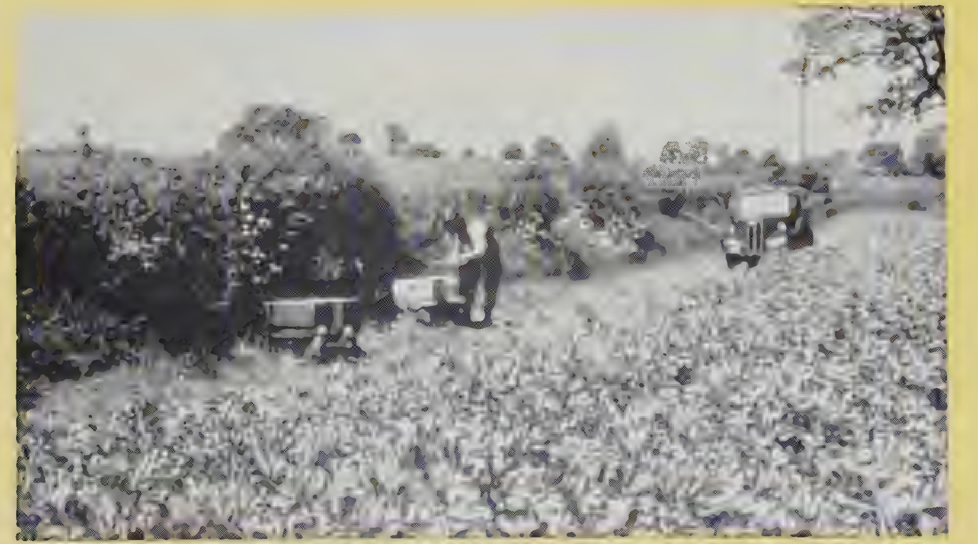

FIG. 3. Hives sited around a field of winter beans at the onset of flowering.

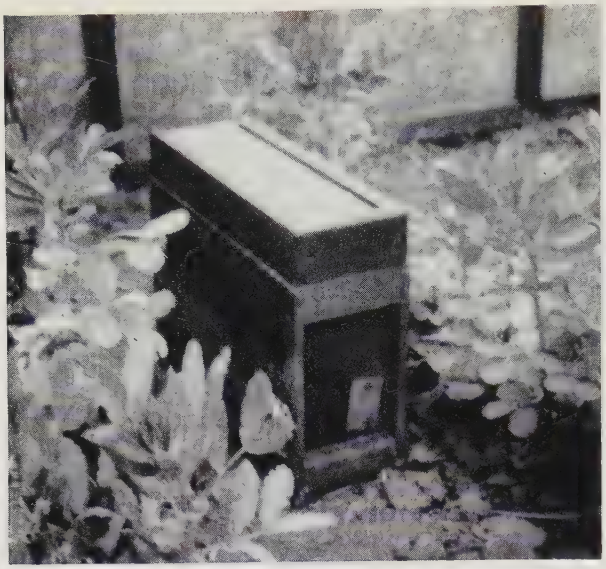

FIG. 4. Nucleus hive in one of the cages.

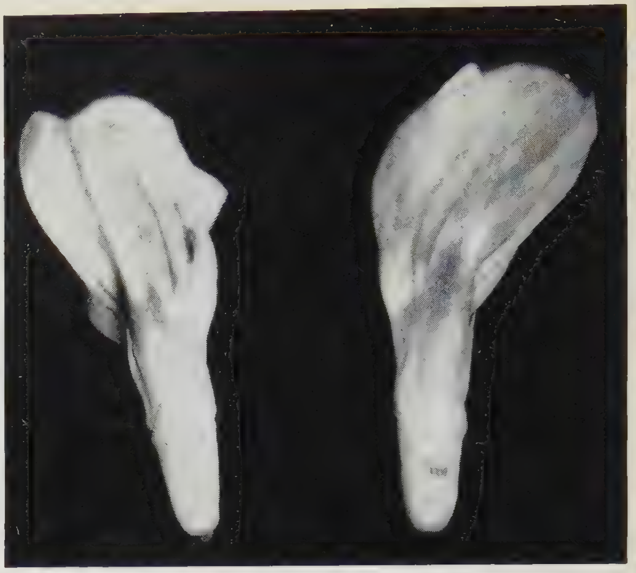

FIG. 5. Bean flowers, one (right) showing a puncture made by the honey bee—the dark mark near the base, and one (left) unpunctured.

5), just as the bumble bee does. This was clearly demonstrated in Treatment 2, where honey bees were confined for cross pollination: on these plots every flower was pierced like the flowers on the open plots. In direct contrast, no flowers in the self-pollinated plots were pierced.

The only difference shown in vigour or rate of growth was that the plants in the cages on the self-pollinated plots finished slightly taller, remained green longer, and were 10 to 14 days later in maturing. This prolongation of the vegetative state was attributed to the fact that many flowers were not fertilized and failed to set seed. There was also a higher incidence of pod drop in the self-pollinated plots.

At the end of the season, which as a good one for beans, the crop in the open field was combine harvested. On all other plots the plants were pulled by hand, tied into sheaves, and left to dry. Later the pods were stripped from the haulms and shelled, and the weight of beans was recorded.

Differences that had not been so easily discernible in the field became evident in the yields, as shown in the table. Yields from all plots to which bees had access and yields from the open field were much higher than those from the self-pollinated plots, confirming our earlier findings that (*a*) in the absence of bees the incidence of pollination and pod set is lower and yields are depressed, and (*b*) honey bees can successfully carry out the function of cross pollination and thereby increase crop yields.

EXPERIMENTS IN 1957–8

Experimental treatments were the same as in the previous season. So, too, were the agricultural operations, except that a different approved variety was sown in the autumn of 1957. Germination and plant establishment were again good, and the crop wintered well and suffered little setback despite severe frosts.

Spring growth in 1958 was not so forward, the plants coming into flower in the second week of May, some three weeks later than in 1957. Moreover, the weather at that time was rather cold and windy and none too favourable for flying bees; yet bees from the hives in the open field worked reasonably well, though some stocks foraged better in poor weather than others.

Observations and Results

As in 1957, the time of flowering was much the same over all treatments. Nevertheless, a closer look showed that tripping of flowers was more frequent among the plants in the open field and on the plots pollinated by honey bees than on the self-pollinated plots from which bees were excluded. Observations confirmed that whereas the honey bee pierces the base of the flower for nectar, it enters the flower tube for the collection of pollen.

Plant growth was affected by the unfavourable weather conditions in 1958 and was rapid and lush during the wet summer, but once again there was little difference between treatments except that the plants on the self-pollinated plots grew taller, remained green longer, and were about a fortnight later in reaching maturity and dying off.

Incidence of chocolate spot (*Botrytis fabae*) was more evident in the plants on the closed plots; plants on the control plots and in the open field which had the advantage of air movement were less affected.

Rain and wind in the autumn flattened the crop in the open field, so that combining was difficult and some beans were lost. Against this, few beans were lost on the experimental plots, as all plants were pulled by hand, tied into sheaves, and dried under shelter.

When the weight of beans per treatment was recorded (see table) it was again found that, even in an unfavourable season, the presence of bees in the vicinity of the crop appreciably increased yields per acre. As in the previous season, yields from the cross-pollinated plots were double those from the self-pollinated.

On another site in an area where bumble bees were numerous and honey bees present, a straight comparison between open cross-pollinated plots and closed self-pollinated plots from which bees were excluded showed a difference in yield of the order of 4 : 1, the cross-pollinated plots yielding over two tons per acre against less than half a ton per acre from the self-pollinated.

The yields obtained in the two seasons—a good bean year (1957) and a bad one (1958)—showed the general effect of the presence or absence of bees.

EXPERIMENTS IN 1958–9 AND 1959–60

It was our intention to repeat this work in 1958–9, and the foregoing treatments were laid down as planned, but towards the end of the flowering period, when the cages and bees had been taken away, the bean crop was subjected to a heavy infestation of black fly (*Aphis fabae*) and the trials were abandoned. We were, however, able to observe the effects of various insecticidal sprays on the bees and the bean crop.

Experimental treatments in 1959–60 were the same as in previous years, and cultivations were again those generally accepted for the crop, but the beans sown came from a local stock. In growth the plants differed little from the named varieties previously used, though it is questionable whether they were as uniform in type. Observations and results showed that the overall pattern conformed with that obtained in earlier trials.

From the results of these experiments obtained in three different seasons, summarized and statistically analysed in the table, it is concluded that cross pollination gives significantly higher yields than self pollination, and hence that bees can be employed to advantage in bean growing.

EFFECT OF METHOD OF POLLINATION ON YIELDS OF WINTER BEANS

(Yields for 3 years in cwt./acre)

Treatments	1957	1958	1960	Mean
1. Self pollination (bees excluded from cages)	22·8	12·3	23·0	19·4
2. Bee pollination (bees included in cages)	43·6	27·4	37·5	36·1
3. Reduced light (free-flying bees)	40·1	27·4	40·4	36·0
4. Control (free-flying bees)	38·5	32·4	39·7	36·8
5. Open field (free-flying bees)	38·0*	27·5*	—	—
Mean	36·2	24·9	35·1	32·1
S.E. per plot: ±2·4.	S.E. of general mean: ±1·4.			

* Excluded from means and statistical analysis.

DISCUSSION

In any discussion of the effect of the various treatments and their practical significance, account must be taken of the role of bees in flower fertilization. It is common knowledge that the gathering of nectar and pollen is vital to the existence of the honey bee and bumble bee, and that in doing so they incidentally carry out Nature's work of pollination and fertilization. With open flowers like fruit blossom visitation for either purpose will achieve this end; but with the tubular flowers of the bean visitation for nectar is not a part of this process, as the flower is pierced from the outside. It is only when collecting pollen that the bee enters the flower tube and acts as a pollinator (*a*) in setting off the tripping mechanism, thus releasing pollen, and (*b*) in carrying on its body pollen from other flowers.

Consideration must therefore be given to bee activity in pollen gathering. At the height of the breeding season (April–May) a queen honey bee will lay several thousand eggs a day. On average

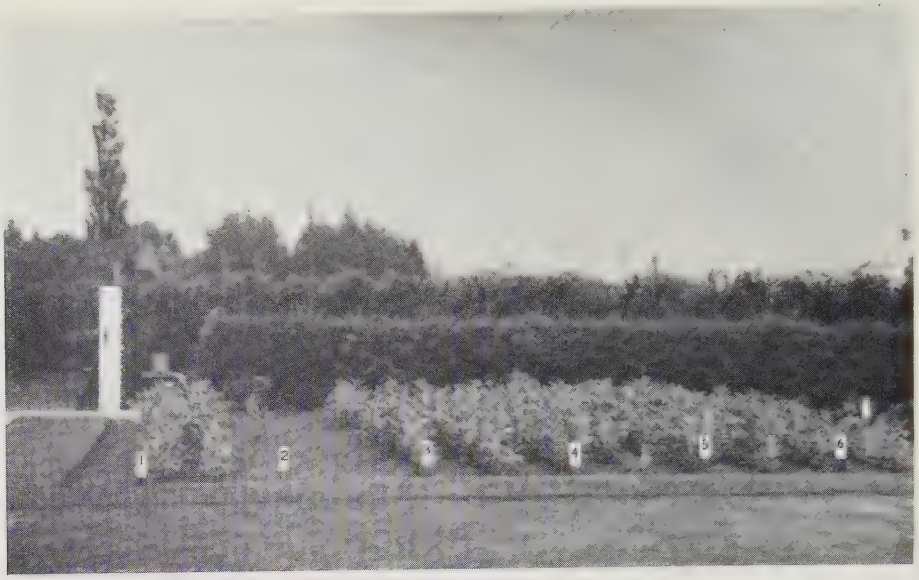

FIG. 6. Winter hardiness trials at Messrs. Garton's Trial Ground, Cheshire, showing failure of beans sown with seed from a self-pollinated stock (Plot 2) in comparison with beans grown from seed saved from Garton's own stock (Plots 1 and 6) and from stock cross-pollinated by honey bees (Plot 3), by honey and bumble bees (Plot 4), and by honey bees hived in the seed-crop area (Plot 5). Seed for Plots 2–5 was supplied by Mr. W. A. Scriven.

some 2000 grubs are emerging every day, all to be fed on a mixture of honey and pollen. To rear one bee takes 10 bee-loads of pollen, and as 1 lb. is needed for 4500 bees, a good stock rearing some 200,000 bees in a season will thus require nearly ½ cwt. of pollen. About 300 flowers are visited to obtain one bee-load and something like 600 million in collecting the pollen necessary to rear each stock.

Applying these data to the bean crop, it is estimated that an acre of beans will produce from 6 million to 20 million flowers during the flowering period (about 3 weeks), and in that time a hive will require the pollen from 90 million flowers of all kinds. On this rough-and-ready basis, one hive would seem to be enough to pollinate 4 acres of beans, but allowance must be made for other factors: not all bees in a hive are pollen gatherers; many plants available to bees in spring have flowers from which the pollen is easier to collect; bees notably dislike working in a wet and blowing crop of beans; in bad weather they only leave the hive for short periods.

For these reasons, and from field experience, we base the pollination requirements at one hive to the acre, placing the hives around the crop if the fields are large. An important point is that bees usually gather pollen from the nearest sources and follow other bees when foraging for nectar and pollen; hence, within reason, the greater their concentration in the vicinity of a given crop, whether it be fruit, clover or beans, the more effective the pollination.

Our observations indicate that cross pollination of the field bean is to some extent associated with plant population, and here the question of spacing comes in. Plants grown in wider rows obtain more light, tend to flower better and are more accessible to honey and bumble bees. Experiments show that, where hives have been in close proximity to the crop, beans grown in rows a yard apart have yielded 35 cwt. per acre. In contrast, a denser plant population is essential where the crop is dependent on self pollination, as pod set is poor on the lower nodes, and many stems fail to produce pods at all. Soper [2] says: "Only three more pods carried on each plant would increase yields by a third in an average season." However, taking into consideration such factors as inter-row cultivation, light and access to bees, row widths of 21–24 in. appear to be satisfactory and practical.

Our investigations also show that, when the crop is grown in an area where bees are relatively scarce, seed from known cross-pollinated stocks of beans will produce heavier yields than seed from mainly self-pollinated stocks. Moreover, comparative trials have shown that plants grown from seed saved from cross-pollinated and self-pollinated parent stocks vary considerably in their degree of winter hardiness, the former being more resistant to frost, while the latter may even fail to survive the winter (Figure 6).

Comparison of the yields shown in the table with the national average of 17 cwt. per acre suggests that a large proportion of this country's bean crop is dependent on self pollination. As Rowlands [1] rightly states: "Cytological examination of individual plants in field bean populations strongly suggests that the crop is inherently a cross pollinator which is forced to inbreed under our conditions through lack of suitable insect vectors."

Has this always been so? Old farmers often speak of yields of 30 cwt. and more per acre in bygone days, and we find no reason to doubt their story, for at one time almost every farm and country cottage garden had its bees in the old-fashioned straw skep. But the Isle of Wight disease brought an end to this picturesque system of beekeeping and seriously reduced the bee population before the first world war. Although a remedy (the Frow treatment) was later found for the disease, treatment was only effective where bees were kept in the then modern W.B.C. hives. The result was that beekeeping became more specialized and fewer bees were distributed throughout the countryside, with, we believe, serious consequences to the bean crop.

Years of observations covering most of the bean-growing areas in Britain have led us to the conclusion that many of the "good bean districts" owe their reputation not altogether to soil and climate or to the quality of a particular stock of beans (though such factors are important), but to the prevalence of bumble bees in hedgerows and banks near the crop or to the keeping of honey bees in the vicinity. In these days of emphasis on mechanization and production due regard must be paid to the increasing hazards these present to insect life. Thus, where hedges and banks must be bulldozed out to enlarge the cultivable area, loss of wild bees should be offset by the introduction of beekeeping. Care must also be taken to avoid bee-poisoning through haphazard application of sprays in suppressing weeds and controlling pests.

Black fly has always been with us and in some seasons is the limiting factor to bean growing. Recent developments in insecticides and their application have done much to reduce this danger, but there is no advantage in controlling the pest if the measures taken are to halve crop yields by killing off pollinating insects, as happened in some parts of the country last season.

The favoured spray materials against black fly in 1959 (a bad year for aphis) were demeton-methyl, dimethoate, malathion, phosdrin and TEPP. All are contact and somewhat fumigant insecticides, in addition to which the first two are said to show marked systemic action. All are exceedingly dangerous to bees working in the field, but only the two systemic materials could cause appreciable harm on days subsequent to spraying. TEPP and malathion are safe to honey bees if hives are ventilated and closed during the day of spraying and opened after dark. Under certain conditions it may be possible to spray late in the evening without closing up the bees; but it is unwise to spray in the early morning, as the plants may still be toxic later in the day.

It was the systemic materials that were most widely used during the hot summer of 1959. Aphid attacks were widespread and early in some areas, and many crops would have been wiped out without spraying. Owing to the drought, beans in some areas failed to yield nectar and no damage to honey bees ensued, though dead bumble bees were found on the ground in fields following spraying; in other areas, where honey bees worked the crop strongly, some damage was caused; and in yet others, where non-systemic materials were used and bees were closed in the hive on the day of spraying, black fly was eliminated without any harm to honey bees, though wild bees frequently succumbed.

It is clear that more work will have to be done to eliminate this conflict. Farmers and spraying contractors frequently do not appreciate the damage done to bees, or the value of bees to a particular crop. There must also be co-operation with the beekeeper. Until a safe and reasonably cheap aphicide is forthcoming—which is by no means beyond the bounds of possibility—sensible precautions in the use and application of existing materials must be taken to preserve the bees that pollinate so many of our crops. As has been shown, this is essential if we are to maintain, far less increase, yields of the field beans.

REFERENCES

[1] Rowlands, D. G. (1955). *Agric. Progress*, **30**, 137–47.
[2] Soper, M. R. H. (1952). *J. Agric. Sci.*, **42**, 335–46.

AVOIDANCE OF DRIFT FROM AIRBORNE SPRAYERS

R. J. Courshee

(*National Institute of Agricultural Engineering, Silsoe, Bedfordshire*)

One of the major problems of crop protection today is that of reducing or eliminating the hazard to crops and wild life caused by spray drift. At present there is no way of stopping a fine spray from drifting when it is applied from the air; but, where a coarse one can be used, it is possible to avoid the risk of damage by taking certain precautions. The method is, however, applicable mainly to low growing crops and has other limitations.

When a pesticide spray is applied from an aeroplane, the cloud of drops which is formed behind the plane lies suspended momentarily in the air. It subsides only slowly, and during the several seconds it takes to fall it may be blown aside by the air disturbance caused by the passage of the plane. Some of the drops, particularly the smaller ones, which are more easily affected by air movement, may be moved out of the spray swathe and become drift. It is usually necessary to reduce this drift to a minimum to avoid contaminating downwind areas.

Ground sprayers give rise to spray drift in a similar manner, but whereas the nozzles on these are 12 in. from the crop those on present-day aeroplanes have to be several feet away and thus afford a much greater opportunity for the formation of drift. Precautions can be taken, however, against causing contamination when spraying with aeroplanes, and these and some of their consequences are described below.

THEORETICAL ASPECTS

Movement of Spray Drops

The main mechanisms controlling the passage of the drops from the aeroplane to the crop are well understood. The spray drops, which commonly range in size from 50 to 300 microns, are shot out of the nozzle under hydraulic pressure. This movement is normally downwards relative to the aeroplane, but the drops also have the forward speed of the aeroplane, and so follow a path which is the resultant of the two movements. On meeting the resistance of the air they progress some distance along this path before they are brought to rest.

The range of penetration attained is controlled by the size of the drop, the density of the spray liquid and the projection speed. For water the relationship is [4]:

$$S=\left(\frac{d\sqrt{v}}{50}\right)^{\frac{3}{2}}$$

where d = drop diameter (microns)
v = drop speed (metres/sec.)
S = range attained (cm.)

The connection between the variables is shown graphically in Figure 1.

After a few thousandths of a second the initial velocity of a 50-micron drop is nearly destroyed by air friction. A 300-micron drop, on the other hand, will continue in motion for nearly a tenth of a second and travel a metre or more. Therefore at distances from a few centimetres to about a metre from the point occupied by the nozzle at the time when they were formed, drops come nearly to rest in mid-air unless they land on a crop (Figure 3). Subsequently they settle at their respective terminal velocities. Large and dense drops are not only projected farthest towards the ground but settle most quickly, and hence are much less likely to become drift than small ones.

All the spray drops are small enough to be blown about by the downwash of air from the aeroplane, which pushes them to the side as they fall. How far they are moved sideways depends on where they were at the start of their movement, how far they are from the ground at the end of it, and how big they are. This motion has been studied theoretically by Reed [6] and demonstrated strikingly by Akesson and Yates [1]. The latter used gas-filled balloons of such a size and weight that they behaved like small drops and then took cine-films of their movement.

The result of Reed's analysis is to suggest that even drops as large as 300 microns will be moved sideways as far as the wing-tip vortices if the aeroplane is a few yards from the ground. Once in the vortices, the drops are likely to be caught in the spiralling movement of the air at the wing tips and be carried aloft. In the time they take to return to the ground even big drops may drift large distances, and farther still if they become reduced in size through evaporation.

This sideways movement of the spray is the main cause of drift. It also has one other important result. The boom on an aeroplane is often only seven yards long, but the sideways rush of air allows the plane to cover with spray a band of the ground 14–20 yards wide. In the absence of the sideways spread the working speed of the aeroplane would be lower in proportion to the decrease in swathe width. The sideways dispersion therefore enables the aeroplane to spray profitably, but at the same time it turns the spray into potential drift. It is this conflict of interests which is worth examining.

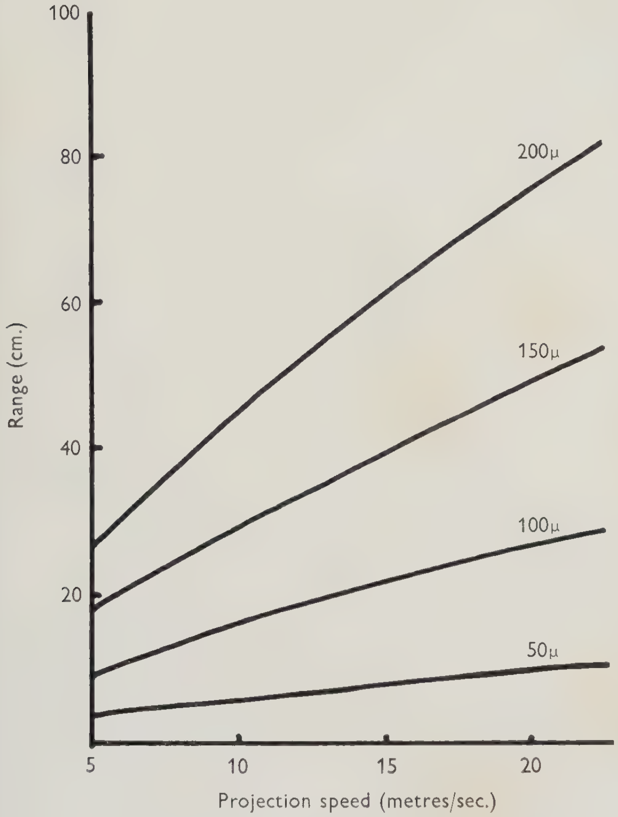

FIG. 1. The projection of spray drops through the air.

Spray Drift

The amount of drift decreases with distance from the spray swathe as more of the airborne fraction of the spray cloud settles out. This deposition is controlled by a complex of factors not yet fully understood. Yeo [7] has recently prepared a survey of the subject. It is sufficient for our purposes to say that (1) the density of contamination is, roughly, inversely proportional to distance, (2) the total amount of contamination is directly proportional to the amount of initial drift at the source, and that (3) the distance to which the contamination extends is controlled by plane height, drop size and wind speed.

Although there is some safety in distance from the source of the spray—at double the distance the contamination is approximately halved—this does not always guarantee the safety of crops in the vicinity, and other factors concerned in drift can help more in reducing contamination.

The initial drift contains nearly all the small drops in the spray. In experiments to measure the size of the drops in the drift we found [3] that it was only those smaller than 200 microns which drifted when a Tiger Moth flew with nozzles a yard above a grassy field.

An approximate indication of the amount of initial drift for other sprays in similar situations would accordingly be given by the amount of the spray which is formed into drops smaller than 200 microns. This fine fraction can vary from under 1 per cent to 100 per cent of the spray. For example, a very fine spray with all of the drops smaller than 200 microns would give rise to 100 per cent drift if the aircraft were 2–3 yards above the ground. That is, the deposition of this spray would depend mainly on the air forces acting on the drops and on their settling speeds rather than on their projection speeds.

If at the other extreme all the drops were larger than 200 microns we should expect no drift to be formed, at least when the spray is applied close enough to the ground. It is therefore important to discover ways of avoiding drops smaller than this. Our experiments on the production and application of a coarse spray promise some hope of reducing the hazard, with acceptable costs in other directions.

It should be remembered that a coarse spray is effective only for certain types of plant protection tasks and that a fine spray is essential where, for example, complete cover of the foliage is required. This would be the case for fungicides if they suffer negligible redistribution, or where contact insecticides, which must hit to kill, are being applied to small, static insects.

PRACTICAL ASPECTS

Avoiding Small Drops

Small drops in the spray from an aeroplane arise from the impact of the stationary air on the spray sheet. This can be minimized by protecting the

FIG. 2. The break-up (left) of a sheet of water and (right) an elastic fluid. (Photograph by courtesy of the National Institute of Agricultural Engineering)

spray sheet prior to break-up by means of a wire gauze a few centimetres long and as wide as the sheet, and by aiming the spray sheet to the rear at the same speed as that of the slipstream. The spray sheet then moves only slowly relative to the stationary air.

Kruse, Hess and Ludvik [5] have shown how the mean drop size increases when the spray sheet is matched to the air speed. An aeroplane flying at 80 m.p.h. requires a spray pressure of the order of 100 p.s.i. for this matching; but the effect is very much more complete at lower pressures, possibly because the liquid leaving the nozzle is then only slightly turbulent and breaks up more regularly in the absence of air forces. Spray pressure should therefore be reduced. At pressures of 10–15 p.s.i. nearly all the small drops can be avoided by flying at the corresponding speed of 25–30 m.p.h.

A further improvement can be made by incorporating in the spray liquids small amounts of chemicals that stabilize the spray break-up. These are effective at concentrations of the order of 1 per cent in the spray and cost only a few pence per acre. With them a difference of speed between the slipstream and the spray liquid of the order of 10 m.p.h. does not cause a measurable rise in the number of small drops. With water alone, on the other hand, matching has to be more precise to obtain the most complete effect.

Effect of Flying Speed

It is clear that such a low flying speed requires a rotary-wing aircraft. The helicopters that are available are relatively expensive except for the Kolibrie, and even this is costly on fuel, so a suitable aircraft might be an autogyro.

The advantages of flying slowly and using a rotary-wing aircraft are not restricted to the avoidance of drift. One important merit is that in operating over a country with small fields, averaging perhaps 15 acres in area, slow flying appears to result in faster work. This may be shown by comparing the performance of the two types of aircraft. The fixed-wing aeroplane flies much faster than the helicopter and, in working over a 15-acre field, takes only a few seconds on each spray run, but 90 per cent or more of its time goes in the long wheeling turn at the end of each run. In contrast, the helicopter takes longer on a spray run but halves the time in a turn, thus the operating time is considerably shortened. This improvement depends on the length of the field and also on the ferrying distance to reload.

It is possible to estimate the optimum speed of working for fields of different sizes. The preliminary analysis suggests, for example, that a field 300 yards long (19 acres if square) is treated most quickly by flying at 40 m.p.h. The penalty of flying at 30 m.p.h. is a decrease from the maximum working rate of only 5 per cent, whereas an increase in speed to the more conventional 80 m.p.h. will reduce the working rate by 15 per cent.

It is therefore simply a fortunate coincidence that flying slowly to avoid drift should also enable spraying to be done more quickly in the small fields common in England. Low speeds are also

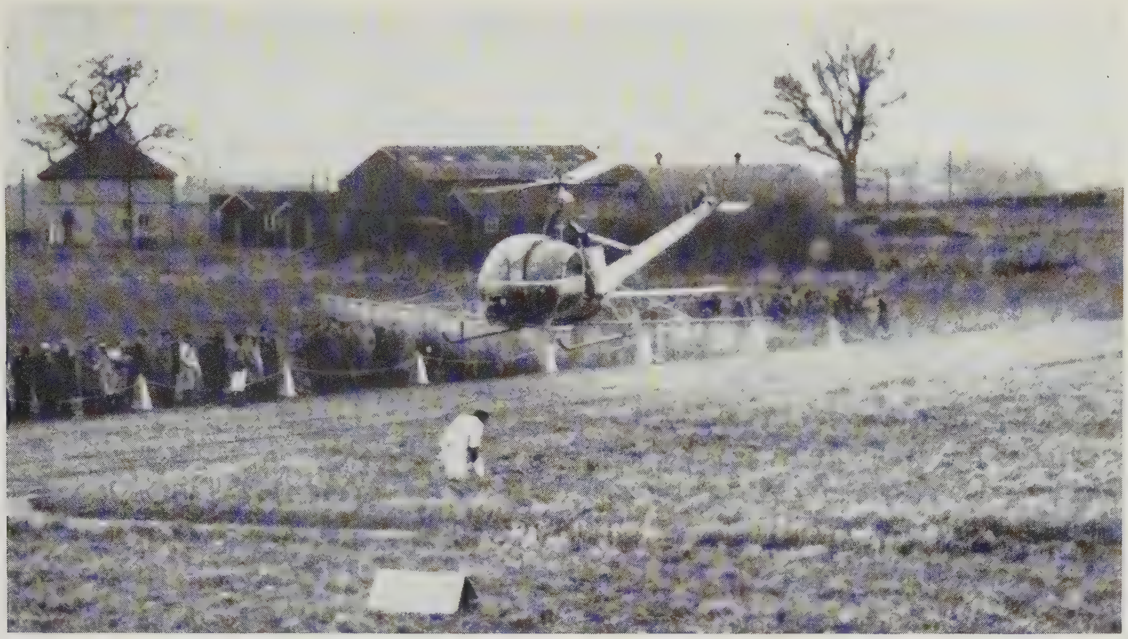

FIG. 3. A helicopter in action. The downward projection of the spray for a distance of about 1 ft. is clearly seen. The farther projection of 200 μ drops is invisible, partly because these are too few in number to reflect light sufficiently to be photographed.

well suited to flying very close to the ground when operating in a countryside littered with obstacles.

Effect of Low Flying

Since any gain that is made by using large drops can be nullified if these are released at too great a height, large drops and low flying together may be necessary to avoid drift sufficiently well. Fixed-wing aeroplanes can be flown close to the crop and some pilots prefer to do so, but the rotary-wing aircraft with its safely low flying speed is more suitable, especially where fields are small.

If the spray has a resultant path towards the ground, the projection by the nozzle can be used to propel 200-micron drops for about one yard, and if the distance between the nozzle and the crop is less than this the spray can be made to impact within a few hundredths of a second of its formation. No drift whatever of drops of this size should arise under these conditions.

If, however, the spray is projected towards the ground, the spray sheet is exposed broadside on to the slipstream, and the formation of drops smaller than 200 microns is then unavoidable. Conversely, if the spray sheet is aimed horizontally backwards, small drops can be avoided, but the large ones then have no velocity component towards the ground.

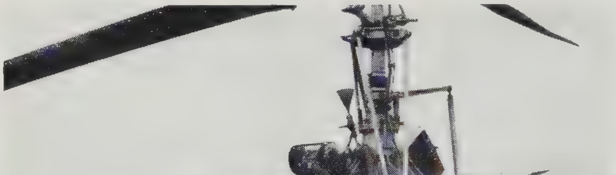

FIG. 4. The downward-facing nozzles can be seen just behind the boom on this helicopter. The domed portions facing upwards are pressure-operated cut-off diaphragms which prevent the nozzles from dribbling.

It is not yet known which arrangement is better in various situations for reducing spray drift.

Invert emulsions of a wide range of physical properties have been used in attempts to avoid spray drift [2], but so far they have not proved successful in our trials. That is, although they do reduce the amount of fine drops in a spray, the ones we have used have not prevented small drops completely. These emulsions at suitable concentrations are soft solids with some shear strength but only a weak ability to recover elastically from a sudden strain. The fluids which we have found to be able to prevent small drops most completely have been liquids with an elastic response both to very brief strains and to those lasting about a millisecond. Typical photographs of the break-up of a spray of water and of an elastic liquid are shown in Figure 2 in the absence of a slipstream.

Assuming that we can have sprays with drops all larger than 200 microns, there still remains the problem of ensuring that they reach the ground promptly. If they are released in the air from a height of 10 ft. and settle at their terminal speed they would reach the ground at distances between 50 and 150 ft. from the spray run if the wind speed were 8 m.p.h.; but some of the drops would get into the wingtip vortices and may be carried up 30 ft. or more, so the distance to which they drift would be correspondingly greater.

Even with a coarse spray, therefore, it is still necessary to fly close to the ground and to choose periods when the wind speed is low. Sideways dispersion of the spray is then cut considerably. This is found even with a conventionally fine spray when a helicopter pilot flies too close to the ground and does not allow enough height to obtain this sideways dispersion. To avoid drift completely the swathe width has to be nearly equal to the boom length, and to keep the rate of work high it will be necessary to fit longer booms than are now conventional on most rotary-wing aircraft. At least one helicopter has, however, already been fitted with an unusually long (20-metre) boom.

CONCLUSION

Although many pesticides are nearly harmless to crops and wild life, some of the most effective and economical are so toxic that they cannot be allowed to drift. Widespread efforts are being made to discover safer materials for pest and disease control, but until these are forthcoming other means must be found to reduce this hazard. With weedkillers applied from the air there will always be some risk of damage to crops in the neighbourhood, however specific they may be in their action; consequently the need to avoid drift will still exist even if insecticides and fungicides are made harmless.

For many purposes in crop protection it has been presumed that a fine spray is required, and at present there is no known way of stopping this from drifting when applied from an aeroplane. But where only a sparse cover of the crop is needed a coarse spray will suffice, and this can be applied with little or no risk of causing drift if certain precautions are taken. Chief among these are that the spray must be projected at low pressure from nozzles close to the crop when there is no wind, using a slow-flying helicopter or autogyro provided with a long spray boom.

The proposal has several limitations, apart from the restrictions it imposes on the choice of pesticides. It is, in particular, applicable mainly to crops that are not more than a few feet high. The form of the crop at the time of spraying will affect the trapping of the drifting spray drops, both by changing their impaction efficiency and by altering the size and intensity of the turbulent eddies in the atmosphere, and it is still far from certain what will happen to the drift over different crop canopies. It can, however, be said that the value of the treatment dwindles with increasing height of the crop, and it will be difficult to avoid drift satisfactorily where tall crops or hilly terrain compel aircraft to fly far from the ground. Nevertheless, the technique may help to reduce contamination of crops downwind from a treated field.

REFERENCES

[1] Akesson, N. B. and Yates, W. E. (1956). *5th Annu. Tex. Agric. Aviat. Conf.*

[2] Beatty, R. M., Kirch, J. H. and Sterry, J. R. (1960). *1st Int. Agric. Aviat. Conf.* (*IAAC, The Hague*).

[3] Courshee, R. J. (1960). *1st Int. Agric. Aviat. Conf.* (*IAAC, The Hague*), pp. 148–56.

[4] Courshee, R. J. and Ireson, M. J. (1961). *J. agric. Engng. Res.*, **6**, 59–63.

[5] Kruse, C. W., Hess, A. D. and Ludvik, G. T. (1949). *J. nat. Malar. Soc.*, **8**, 312.

[6] Reed, W. H. (1954). *NACA Rep. No.* 1196.

[7] Yeo, D. (1960). *1st Int. Agric. Aviat. Conf.* (*IAAC, The Hague*), pp. 112–30.

BLISTER BLIGHT DISEASE OF TEA

G. B. Portsmouth

(*Formerly Director of the Tea Research Institute of Ceylon*)

When this serious disease of tea first appeared in Ceylon in 1946 little was known of its biology or control; but immediate steps were taken to remedy matters, and within four years efficient measures had been devised for the protection of tea in bearing and recovering from pruning. Spraying or dusting with copper fungicides is now routine practice, and research has turned to improving formulations and the timing of applications.

Blister blight derives its name from the characteristic white sporing lesions, or "blisters" (Figure 1), produced on the surface of the host by the causative fungus *Exobasidium vexans* Massee [20]. The fungus, which belongs to the Homobasidiomycete family Exobasidiaceae, is an obligate parasite having no known alternate host.

The disease has been endemic in Assam for more than a century, where, apart from two or three sporadic outbreaks, it gave little cause for alarm. In September 1946, however, blister blight was reported from the tea districts of South India and one month later from Ceylon. The almost simultaneous appearance of the disease, together with the rapidity of its spread, caused great concern in both countries. This was perhaps most marked in Ceylon, since by the end of January 1947 reports of the presence of blister blight had come in from nearly all the principal tea areas. Further, many Ceylon tea planters could not help remembering the disastrous collapse of that country's coffee plantations in the 1870s caused by the rust *Hemileia vastatrix* [9]. This national catastrophe, which had been followed by years of hardship, had undoubtedly been the prime factor leading to the development of Ceylon's main agricultural industry—tea, so the bare possibility that history might repeat itself represented a major threat to the country's whole economic stability.

In these circumstances it is not surprising that almost the whole resources of the Tea Research Institute of Ceylon were immediately concentrated on efforts towards finding a satisfactory form of control for blister blight. It is pleasing to record that the Ceylon Government were also quickly awake to the potential danger and readily provided financial and other support to the Institute. Assistance was also freely given by the various firms specializing in large-scale crop protection, as well as by fungicide manufacturers, with the consequence that by the end of 1950 it was evident that tea, both in bearing and recovering from pruning, could be satisfactorily and economically protected. The threat of disaster had thus been averted in under four years, and subsequent research could accordingly be devoted to improving the efficiency of crop protection methods and reducing costs per acre.

The whole blister blight campaign affords an outstanding example of the value of co-operative effort in the never-ending fight against crop pests and diseases. Not only was the main objective successfully achieved in a remarkably short period but new principles of general application to a much wider range of crop protection problems were discovered. Further, the very exacting and large bulk demands of the tea-growing industry for fungicides and spraying and dusting equipment for blister blight control have stimulated many recent improvements in formulations and in the efficiency of crop protection equipment.

Little is known about the origin of the initial outbreak in South India. The most plausible conjecture would seem to be that the disease was introduced on infected planting material brought down from Assam and remained unnoticed until it had built up to near-epidemic proportions. The assumption that a fairly extensive source of infection must have already been present in South India at this time is based on the fact that the practically simultaneous appearance of the disease in widely scattered districts in Ceylon precludes any other explanation except that the Ceylon infections were due to spores carried on the wind from South India. That, given suitable weather conditions, airborne infections can take place over even longer distances is shown by the subsequent spread of the disease to Sumatra in 1949, to Malaya in 1950, and to Java in 1951 [23].

THE BLISTER BLIGHT FUNGUS

Before the outbreaks of 1946 little was known about the biology of *Exobasidium vexans*. Further information was urgently required if control measures were to be developed on a firm scientific basis, and accordingly a comprehensive mycological investigation was immediately begun at the Tea Research Institute of Ceylon [1, 2]. As the result of this and later work [11, 21] the facts relevant to the control of the disease were found to be:

1. The spore is airborne and is surrounded by a thin mucilaginous sheath which causes it to adhere firmly to any surface on which it comes to rest.
2. The spore is rapidly killed by exposure to direct sunlight for a short period. Under suitable conditions it remains viable for some days.
3. Ripe spores are forcibly discharged from the basidial sterigmata clear of the hymenium. This discharge mechanism ceases to function when the water supply to the leaf or shoot is interrupted.
4. Spore discharge from a mature blister may continue for 7–10 days, depending on conditions. During its active life a large blister may produce several million spores.
5. Under suitable conditions, the most important of which would appear to be a high relative humidity coupled with an absence of liquid water on the surface and not too high temperatures, germination and the formation o appressoria take place in 6–16 hours. A mucilaginous sheath is again developed around the germ tubes and the appressoria which anchors them to the surface, enabling the infection threads to penetrate directly through the cuticle. There is no evidence for stomatal attraction, and the majority of leaf infections take place through the upper surface. Once this stage has been passed the fungus is no longer susceptible to contact fungicides.
6. The first visible sign of infection becomes apparent as a translucent spot within about 6–10 days. After about a further 7 days the hymenium ruptures the epidermis and sporing begins. In leaf infections the hymenium always develops on the lower surface.
7. Leaf and stem tissues are susceptible to infection only when up to 20–40 days old, depending on the rate of maturation. Young fruits may also become infected, but this does not usually prevent maturation of the seed.
8. The spores are extremely susceptible to most types of copper fungicides; the most frequently used formulations are those based on cuprous oxide or copper oxychloride.

A factor hampering rapid solution of the blister blight problem was that *E. vexans* could not be grown satisfactorily in artificial culture, nor could consistent results be obtained from spore germination tests carried out in the laboratory. As a consequence, all trials of fungicide formulations had to be carried out under field conditions, which often necessitated waiting several months for the results.

CONTROL BY LOW-VOLUME SPRAYING

In spite of the many difficulties involved, work on the problem had progressed so rapidly that early in 1950 it was possible for the Tea Research Institute of Ceylon to organize estate-scale trials, covering more than 750 acres, in which the protection of tea recovering from pruning was attempted during the period of the south-west monsoon rains, when blister blight infection was at its peak [22, 25]. In all these trials the cuprous oxide fungicide Perenox was used at a concentration of 4 oz./10 gal. water and applied every 7 days at a rate of approximately 15 gal./acre by means of pressure-retaining knapsack sprayers fitted with low-volume nozzles.

Severe weather conditions were encountered during these experiments. Thus, for the main 200-acre Kataboola experiment, the total rainfall from July to October was 72·6 in. and 106 out of the 112 days were wet. September was the wettest month with a 22·4 in. rainfall, and October the driest with 12·4 in.

Such heavy and continuous rainfall made it impossible to adhere to the original intention of postponing spraying during heavy rain, so it was decided to continue spraying right through the week irrespective of weather conditions. All the experiments were completely successful, confirming the possibility suggested by previous laboratory investigations [3] that sufficient copper to provide adequate protection might be retained on the surface of the sprayed or dusted shoots after heavy rainfall. A new and important principle in crop protection practice had thus been established.

The effectiveness of the control given by copper spraying in these experiments was manifest in the complete destruction of all new growth in the unprotected control plots in marked contrast to the normal recovery shown by the protected bushes.

The spraying of tea in plucking presented a rather more complex problem, since, while enough copper to give adequate control of the disease had

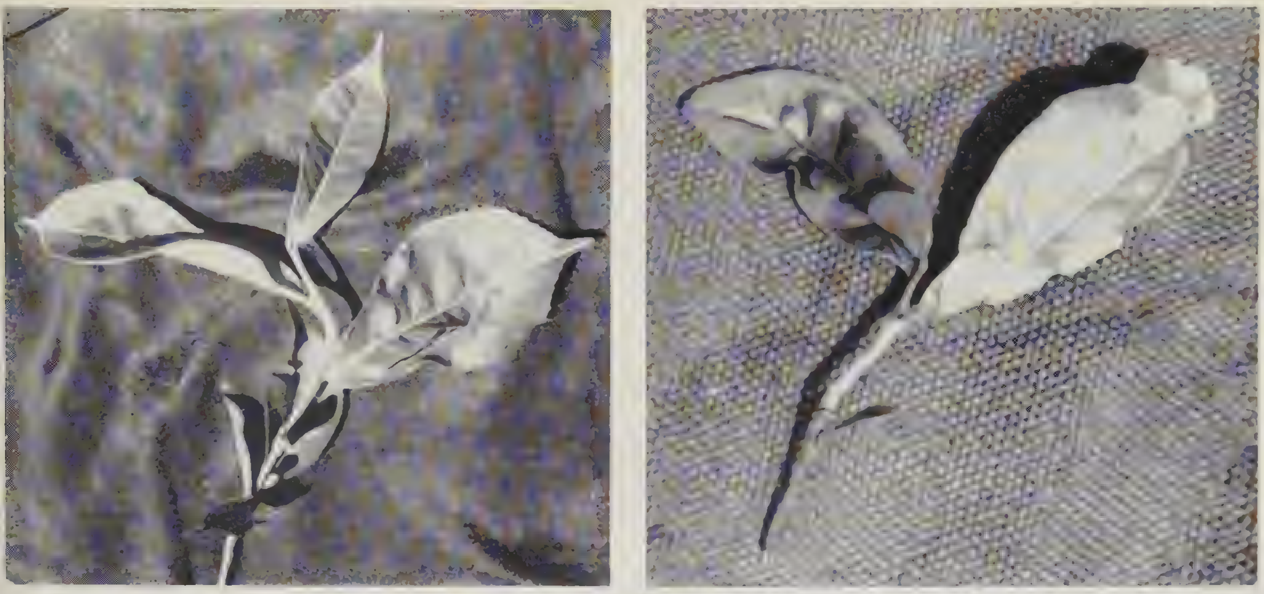

FIG. 1. Blister blight lesions on (left) upper surface and (right) lower surface of tea leaf.

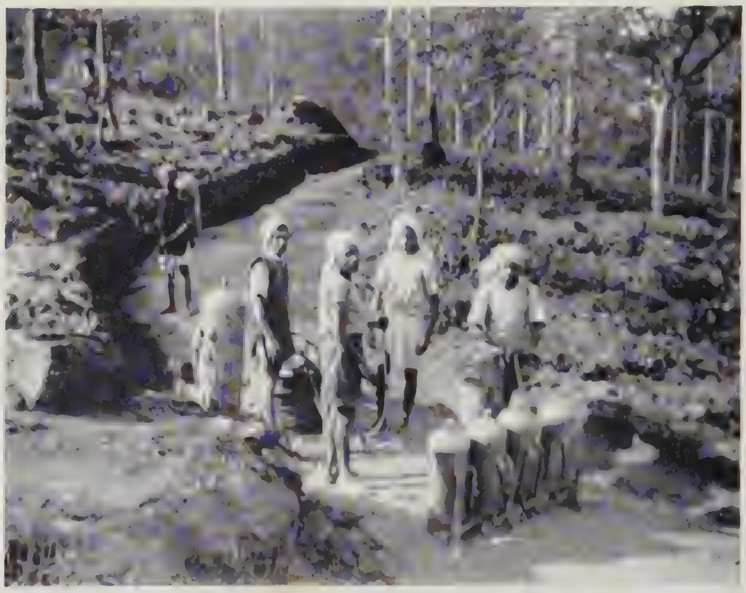

FIG. 2. The mixing and charging point for a typical spray gang in a tea garden. The pressure knapsack sprayers can be seen in the foreground. The spray fluid container and liquid charge pump are just visible between the coolies on the left of the group. Kotmale, Ceylon. (Photograph by courtesy of Mr. C. L. Scoles.)

to be applied to the bushes, means had also to be devised to ensure that any copper residues in the teas made from the sprayed shoots remained within acceptable limits. Further, as plucking in the worst-affected areas of South India and Ceylon was normally carried out at close intervals, ranging from about 7 to 14 days, the danger of excessive copper residues was a very real one. The whole question was accordingly taken up with the Metallic Contamination Sub-committee of the Food and Labelling Division of the Ministry of Food, who gave their approval to a temporary tolerance of 150 p.p.m. of copper in teas sent to the United Kingdom market [5].

Meanwhile the knowledge that the majority of infections took place through the upper surface of the leaf had suggested that adequate protection of tea in plucking might be obtained by low-volume spraying at 12–15 gal./acre. To test this possibility a small-scale, fully replicated experiment, in which Perenox at a concentration of 4 oz./10 gal. was applied at both weekly and fortnightly intervals during the blister blight season, was started in 1949 on the Tea Research Institute of Ceylon's own estate of St. Coombs [10]. It was soon evident that protection of tea in plucking by low-volume spraying was possible, as can be seen from the results for the years 1949 and 1950 given in Table I.

TABLE I

EFFECT OF PROTECTING TEA IN PLUCKING BY LOW-VOLUME SPRAYING WITH PERENOX.
ST. COOMBS NO. 9 FIELD CROP PROTECTION EXPERIMENT

(Yields in lb./acre made tea)

Period	Yield			Increase over controls		Total number of sprayings	
	Control not sprayed	Sprayed every 7 days	Sprayed every 14 days	Sprayed every 7 days	Sprayed every 14 days	Every 7 days	Every 14 days
1st year from pruning . . (23.5.49–31.12.49)	328·8	414·4	410·0	85·6 (26%)	81·2 (25%)	29	15
2nd year from pruning . . (1.1.50–11.11.50)	534·0	702·2	665·2	168·2 (31·5%)	131·2 (24·6%)	30	16

Protection was not so good on the fortnightly-sprayed plots as on those sprayed weekly, and it was therefore considered that the most economical spray interval would fall between these limits. Accordingly a new experiment, the St. Coombs No. 8 Field Crop Protection Experiment, was started in 1950 in which spraying was carried out at intervals of 9 or 10 days, which corresponded with the normal estate plucking intervals on St. Coombs. The spray applications were also timed for the day following plucking, so that there was the longest possible interval between spraying and plucking. As this arrangement gave the lowest possible spray residues and enough leaf was harvested from the different plots to permit of separate manufacture, the experiment was also very useful in providing information about the extent of the copper residues in made tea [3]. The results of the numerous analyses made are summarized in Table II.

Since the highest figure (80 p.p.m.) was given after no rain had fallen between spraying and plucking it was obvious that, if spraying at the rates used in the experiment was carried out immediately after plucking, there was little likelihood of the copper contents of the made teas exceeding 100 p.p.m. even in dry weather.

TABLE II

COPPER CONTENTS OF TEAS MADE FROM BUSHES SPRAYED EVERY 9–10 DAYS

(Expressed as p.p.m. on the dry weight)

	Unsprayed	Sprayed
Mean value	28	55
Highest figure	31	80
Lowest figure	24	39

The way was thus clear for the tea industry to embark on the large-scale protection of its worst-affected estates, and all available information was made public at a conference held in Nuwara Eliya in December 1950. The recommendations published at this conference were eagerly accepted by the industry and put into practice on a large scale in 1951, as may be judged by the fact that several hundred tons of copper fungicides, containing about 50 per cent of metallic copper, were used on Ceylon tea estates during the year.

CONTROL BY DUSTING

Early trials with fungicidal dusts having shown little promise of giving effective control, work on dusting was virtually abandoned until 1951. However, with the proved success of low-volume wet spraying the time appeared opportune for a re-examination of the possibilities of dusting, since that method had a strong appeal to many planters on account of its reduced labour requirements per acre.

As these new investigations proceeded it soon became apparent that one of the principal reasons for the lack of success of the original trials was that too great reliance had undoubtedly been placed on the rather problematical benefits to be derived from attempting to cover big acreages rapidly by means of drift dusting from large power dusters—a mistake in emphasis which was made all the worse by the subsequent discovery that many of the copper dust formulations were entirely unsuitable for this purpose.

In this latter connection the most revealing experiment was that [4] in which standard quantities of some 13 different commercially available copper formulations were blown from a power dusting machine through the 680 ft. railway tunnel at Talawakelle. Glass plates of uniform size (100 cm.^{2}) were placed at intervals throughout the length of the tunnel directly in line with the nozzle of the machine. After each test these plates were collected and the amount of copper deposited on each plate was determined by analysis. Converting the various copper dust formulations to an equivalent 4 per cent copper content gave the average distribution of copper with distance from the machine shown in Table III.

TABLE III

AVERAGE COPPER DEPOSITS, AT DIFFERENT DISTANCES FROM A POWER DUSTING MACHINE, FOR A 4% Cu DUST FORMULATION

Distance (ft.)	Copper (μg./100 cm.^{2})
5	667
10	1995
25	5474
50	1529
75	632
100	427
150	118
200	70
250	47
350	6
450	2
550	0

On the assumption that an initial copper deposit of about 5 μg./cm.^{2} is likely to be required to give control, it is clear that there was little possibility of obtaining adequate protection with these dusts over a distance of more than about 100 ft. from the machine, however efficient the machine might be, as was demonstrated by the vast clouds of copper-free filler particles which emerged from the far end of the tunnel during each trial. Further, the very heavy fall-out of the active ingredient around 25 ft. from the machine was most undesirable if excess copper residues were to be prevented in the made teas.

All the dusts tested were "blended" dusts, and it is probably largely as a result of this particular experiment that the necessity of matching either the specific gravity or particle size of the filler and active ingredient to make such dusts really effective was first realized by manufacturers. As a consequence, efficient "blended" dust formulations are now available for power dusting, and the entirely new and still more effective, though more expensive, "coated" dust formulations have been developed.

Once the difficulties underlying the problem of controlling the disease by the application of copper-containing fungicidal dusts were fully understood it was possible to devise and carry out a more realistic programme of field and estate-scale experiments [13–19]. This programme reached completion at the end of 1953, by which time it was evident that, if either hand dusters alone or a combination of power machines and hand dusters were employed, adequate protection of both tea in plucking and tea recovering from pruning could be secured with dust applications at rates as low as 5 lb./acre every 8 days in all but the worst blister-affected areas, provided always that only the best available 4 per cent and 6 per cent copper dusts were used. Early in 1954 the Tea Research Institute of Ceylon was able to give restricted approval to the use of such dusts for the protection of tea against blister blight [6]. Nevertheless, for the application of equivalent amounts of copper per acre, dusting is somewhat less efficient than wet spraying, and for this reason wet spraying is still to be preferred in areas subject to prolonged attacks of the disease.

There now being a choice available between these two methods of crop protection, it seems likely that, since no water is needed, dusting will tend to be preferred in the drier districts of South India and the Uva province of Ceylon, while spraying will still continue to be largely adopted in the wetter south-western districts of Ceylon.

GENERAL RECOMMENDATIONS FOR CONTROL

Parallel with the development of dusting as a satisfactory method of crop protection, low-volume spraying had been so successfully brought into operation over some 250,000 acres of tea that by 1955 it had become a routine practice on the majority of affected estates. As a consequence of the extensive practical experience acquired during this period many improvements to equipment and field organization had been introduced, and both labour requirements and costs of protection per acre had reached such low levels that little further progress in this particular method of crop protection could reasonably be expected. The time therefore seemed ripe for all the various recommendations to be collected together in a convenient form, and a pamphlet called *Protection of Ceylon Tea from Blister Blight* was published in November 1955 [24]. Most of the advice given in this pamphlet is still valid, and anyone concerned with the subject is strongly advised to consult the original; certain of the more important points mentioned are summarized below:

(*i*) *Prevention of Excess Copper Residues in the Made Tea*

Application of copper fungicides must be made at the earliest opportunity after plucking, and on no account should application be made less than five days before plucking, which would give four clear days' interval before plucking.

(*ii*) *Spraying*

(*a*) The fungicides recommended are almost invariably based on copper oxide or oxychloride, and usually contain 50 per cent metallic copper. (*b*) With some of the low-volume equipment now in use applications as low as 10 gallons of spray fluid are often made per acre. Accordingly the fungicide should be mixed at a concentration such as to give an application rate of 6 oz./acre. (*c*) Tea recovering from pruning should be sprayed every 4–5 days up to tipping, using a 50 per cent copper fungicide at 6 oz./acre. (*d*) Tea in plucking should be sprayed every 7–10 days, depending on the plucking round, with the fungicide at 6 oz./acre.

(*iii*) *Dusting*

(*a*) The dusts recommended are usually based on copper oxychloride, but occasionally on the oxide, and formulated either as blended or coated dusts containing 4–6 per cent copper. (*b*) Dusting of tea recovering from pruning is not generally recommended, but, if carried out, larger quantities of copper per acre than for tea in plucking are usually necessary. (*c*) The normal application rate recommended for tea in plucking on a 10-day round is 5 lb. of 4 per cent "blended" copper dust per acre every 5 days. (*d*) If a "coated" dust is used the intervals between dustings may be extended up to about 8 days without loss of control.

APPLICATION EQUIPMENT

Low-volume Spraying

Because the very hilly nature of most of the worst-affected tea areas precludes the use of any mechanically propelled machine, the most efficient method of application has proved to be by means of pressure-retaining knapsack sprayers (Figure 2). These knapsacks are best operated in batteries of 10 or more served by a power-operated charge pump mounted on a trailer chassis, which can be moved as close as possible to the scene of operations by a tractor working over the estate's road system [7].

The coverage given by a single knapsack has also been greatly increased by mounting a matched pair of suitably designed double-fan jet nozzles on the end of the lance. When correctly adjusted, these nozzles give a swathe width of 14–16 ft., which enables 4 rows of normally spaced tea bushes to be sprayed simultaneously. Such nozzles have a high rate of output, ranging from 16 to 20 gal./hour, so that rapid power recharging is needed.

With such high discharge rates, coupled with the necessity for maintaining a constant swathe width and regular degree of atomization, the usual drop in pressure that occurs during discharge assumed considerable importance. A pressure-regulating valve was accordingly designed [8] which, when substituted for the ordinary knapsack outlet cock, was capable of maintaining constant pressure regulation throughout the whole of the discharge. As this valve has necessarily to be adjusted to the lowest working pressure of the knapsack to ensure complete delivery of each charge of spray fluid, the overall output rate is appreciably reduced, saving at least one charge in a day's working. At the same time the constant steady output ensures even application.

Results achieved with this type of equipment naturally depend both on the terrain and the efficiency with which the whole operation is organized; but, given favourable conditions, there is no reason to suppose that daily coverages of 5 acres or more per labourer employed cannot be obtained.

Dusting

Only hand-operated dusting equipment has so far been recommended as capable of giving satisfactory protection under all conditions, the normal coverage from each machine being not more than 4–5 rows of bushes.

Power machines have also been used on a few estates with a moderate degree of success; but, as their range of effective control appears to be limited to a swathe width of not more than 50 yards with 6 per cent dust and to only about 25 yards with 4 per cent dust [12], they need to be supplemented by hand dusters or knapsack sprayers.

Using only hand dusters it is possible to secure daily coverages of up to 10 acres per labourer.

Mistblowing

No mistblowing equipment is recommended, and, as the larger power-operated machines appear to suffer from even more drawbacks than the big power dusters, such machines show little prospect of ever being found suitable for use on tea. On the other hand, certain small power-driven machines, man-carried on knapsack-type mountings and having an output of about 2 gal./hour, had a limited success when operated over 5 rows of tea so as to apply a concentration of 6 oz. of copper per gallon per acre [19]. But, in view of the much greater initial cost of these machines and their more stringent maintenance requirements, it seems unlikely that this type of equipment will ever be preferred to hand dusters or knapsack sprayers.

GENERAL CONSIDERATIONS

The limitations imposed by the nature of most of the terrain over which machines are required to operate make it highly improbable that there will be any radical changes in the types of equipment used for applying fungicides to tea for some time to come. Future developments in the control of blister blight may therefore be expected to result from two distinct lines of research. These are (*a*) the introduction of improved fungicide formulations, and (*b*) the development of some method that will take the effect of climatic factors more into account in the timing of crop protection programmes.

As far as fungicides are concerned, the ultimate aim is still for the development of a non-tainting, non-poisonous fungicide with a pronounced systemic action. Such a product would enable the intervals between applications to be greatly lengthened, thus releasing labour for other estate work; but this ideal is very far from realization.

Considerable attention continues to be devoted to improving the various copper-based formulations available on the market, as may be instanced by the introduction of "coated" dusts. Small-scale trials, started in 1955, also suggested that considerable advantages might be derived from applying the "coating" principle to wet spraying formulations. Unfortunately these earlier promises were not fully borne out by the extensive spraying trials carried out at St. Coombs during the south-west monsoon season of 1957 [27]; these showed, contrary to expectation, that a "coated" formulation containing 16 per cent of copper, applied at 8 oz./acre, failed to give as good protection as the standard fungicide (Perenox) applied at 6 oz./acre. It should be noted, however, that yields from the plots protected by the "coated" fungicide were equal to those from the plots protected by Perenox, although the former showed 33 per cent blister infection as compared with 22 per cent for the latter. As both these figures are within the arbitrarily chosen level of 35 per cent infection, below which it is assumed that satisfactory protection is achieved [29], the possibilities of "coated" wet spray formulations clearly merit further investigation.

The full results of the 1957 trials are also of importance in showing that, during periods of severe infection, the degree of protection achieved by "standard" fungicides is more or less proportional to the amount of metallic copper applied, irrespective of whether it is formulated as the oxide, oxychloride or carbonate, or as colloidal copper. Since many of the treatments tested represented reduced application rates, these results also confirm that the recommended standard of 6 oz. of 50 per cent copper fungicide per acre is the minimum, if adequate protection of tea in plucking is to be secured under conditions of severe infestation.

Turning now to a consideration of the influence of climatic conditions, it has been known for some time that the rate of development of a blister blight attack depends primarily on (*a*) pre-existence of a sufficiently intense source of spores to permit of numerous simultaneous infections, once climatic conditions are suitable, and (*b*) the persistence of these conditions long enough to allow a build-up of infection potential.

Disregarding the effects of spores airborne over long distances, the first condition is fulfilled by the existence of localized pockets of tea alongside watercourses and jungle boundaries and in other places where the humidity and shade permit the fungus to remain active throughout the year and to serve as a source of initial infection each successive season. These sources of primary infection are naturally much more prevalent in areas with long rainy seasons, like the south-western districts of Ceylon, and it is probably for this reason that severe blister blight attacks are more frequent in this area than in the drier districts of Uva and South India.

To fulfil the second condition, the principal requirements would appear to be persistent high humidity coupled with lack of sunshine for at least a sufficiently long time each day to permit germination of the spores and penetration of the infection tubes, a process that may take up to 16 hours or even more. Aspect also has a considerable influence on the build-up of attacks; for example misty conditions suitable for infection to occur tend to persist later in the day on western-facing hillsides.

The fact that blister blight incidence is closely related to local climatic conditions has been thought to offer attractive possibilities of forecasting outbreaks, provided that some practical criterion of conditions favourable to the build-up of the disease could be found; but little could be done until 1958, when preliminary experiments to test the possibility of using daily sunshine records for forecasting purposes were laid down at St. Coombs [26]. In these experiments routine spray applications were scheduled for either 5-day or 7-day intervals, but withheld whenever an average of 3–4 hours sunshine per day had been received during the intervening period. As a consequence, although adequate protection was maintained throughout, the number of spraying rounds required was reduced by about 40 per cent over a period of some 8 months. This method of timing spray applications clearly shows much promise, but, until certain of the practical difficulties involved have been further investigated, cannot be recommended for adoption by estates.

In conclusion, mention must be made of the fears frequently expressed in certain quarters that the application of copper fungicides to tea might cause some depression of yields owing to the phytotoxic effect of copper. As yield levels continued to rise while more and more tea was brought under regular protection, there would appear to have been little cause for anxiety on this score, and such as there was must have been finally dispelled by an experiment carried out early in 1958 [28], in which various proprietary copper fungicides were sprayed at the recommended rates on tea in plucking and the yields recorded and compared with those of untreated controls. Since the experiment was confined to the driest and sunniest period of the year, when blister blight incidence was negligible, any differences in yield could be attributed only to the effects of the spray treatments; but there were no significant differences, and it was concluded that spraying with copper fungicides at the normal rates had no appreciable phytotoxic effect on tea.

REFERENCES

[1] GADD, C. H. and LOOS, C. A. (1948). *Trans. Brit. mycol. Soc.*, **31**, 229.

[2] GADD, C. H. and LOOS, C. A. (1950). *Trans. Brit. mycol. Soc.*, **33**, 19.

[3] HOWARTH, F. (1950). *Tea Quart.*, **21**, 28.

[4] HOWARTH, F. (1951). *Tea Quart.*, **22**, 118.

[5] LAMB, J. (1950). *Tea Quart.*, **21**, 33.

[6] LAMB, J. (1954). *Tea Quart.*, **25**, 14.

[7] LANDRETH, J. (1954a). *Tea Quart.*, **25**, 15.

[8] LANDRETH, J. (1954b). *Tea Quart.*, **25**, 62.

[9] LARGE, E. C. (1940). *The Advance of the Fungi*. Jonathan Cape, London.

[10] LOOS, C. A. (1950). *Tea Quart.*, **21**, 16.

[11] LOOS, C. A. (1951a). *Tea Quart.*, **22**, 63.

[12] LOOS, C. A. (1951b). *Tea Quart.*, **22**, 126.

[13] LOOS, C. A. (1952a). *Tea Quart.*, **23**, 6.

[14] LOOS, C. A. (1952b). *Tea Quart.*, **23**, 76.

[15] LOOS, C. A. (1952c). *Tea Quart.*, **23**, 127.

[16] LOOS, C. A. (1953). *Tea Quart.*, **24**, 70.

[17] LOOS, C. A. (1954a). *Tea Quart.*, **25**, 10.

[18] LOOS, C. A. (1954b). *Tea Quart.*, **25**, 13.

[19] LOOS, C. A. (1954c). *Tea Quart.*, **25**, 5.

[20] MASSEE, G. (1898). *Kew Bull.*, 109.

[21] PFAELTZER, J. W. (1951). *Tea Quart.*, **22**, 52.

[22] PORTSMOUTH, G. B. (1950). *Tea Quart.*, **21**, 11.

[23] PORTSMOUTH, G. B. (1952.) *Rep. 13th Internat. Hort. Congr.*, 1218.

[24] PORTSMOUTH, G. B. and WEBSTER, B. N. (1955). *Pamphlet No. 2, Tea Res. Inst., Ceylon.*

[25] SCOLES, C. L. (1950). *Tea Quart.*, **21**, 22.

[26] VISSER, T., SHANMUGANATHAN, N. and MULDER, D. (1959). *Tea Quart.*, **30**, 39.

[27] VISSER, T., SHANMUGANATHAN, N. and SABANAYAGAM, J. V. (1958a). *Tea Quart.*, **29**, 9.

[28] VISSER, T., SHANMUGANATHAN, N. and SABANAYAGAM, J. V. (1958b). *Tea Quart.*, **29**, 45.

[29] WEBSTER, B. N. and PARK, P. O. (1956). *Tea Quart.*, **27**, 3.

FACIAL ECZEMA OF SHEEP AND CATTLE IN NEW ZEALAND

C. P. McMeekan

(*Ruakura Animal Research Station, New Zealand Department of Agriculture*)

After twenty years' preoccupation with the idea that the toxin responsible for this disease was produced by a pasture plant, the discovery in 1958 of its origin in a specific fungus has changed the whole face of research. Events since then have moved rapidly. The toxin has been isolated and identified, and work is being concentrated chiefly on its biochemical relationships to the animal and on new possibilities of control.

The recent announcement [26, 38], of a probable fungal origin of the hepato-toxin believed responsible for the disease of ruminants known as facial eczema has excited world-wide interest among animal scientists. This review has been prepared as one way of meeting the many requests for information on current knowledge of a syndrome, the precise cause of which has defied research for fifty years.

At the outset it must be made clear that the disease is not an eczema. Facial eczema in sheep and cattle is a hepatitis which may be accompanied by jaundice and by photosensitization of unprotected white or lightly pigmented skin areas. The colloquial name originated from the last-mentioned symptom. It is understandable that the disease should have been so labelled by farmers, since its most obvious outward manifestation is an acute photosensitization of the face and ears of affected sheep. Despite its inherent inaccuracy, in both popular understanding and in scientific literature, the name is so well established as to be hardly worth changing.

Facial eczema is an important disease of grazing sheep and cattle over most districts of the North Island of New Zealand. It has occurred, but rarely, in the South Island, and then only in the northernmost zones, where the climate is similar to that of the North Island. Until recently it was believed that the condition was unique to New Zealand, but lately cases have occurred in the Gippsland area of Victoria, Australia [18].

The disease was observed in New Zealand as early as 1898 [16], but personal records of farmers of pioneer days suggest that it may well have occurred before that time. The disease did not excite attention as a source of serious economic loss until the disastrous outbreak of 1938, when several million sheep and large numbers of dairy herds were severely affected throughout most districts of the North Island. Since then there have been sporadic outbreaks with major economic consequences on several occasions, the most widespread being in 1954 and 1956.

The disease is usually confined to late summer and autumn and to years which are hotter than normal. In such years it follows late summer and early autumn rains which are sufficiently warm to promote very vigorous pasture growth. It is most common and most severe on the more highly improved pastoral country.

Economic loss arises in various ways. Normally, the immediate death rate in sheep is low, and most animals recover to the stage when they can be fattened. Breeding stock, however, can be very poor risks [15], depending on the amount of liver tissue destroyed. Rams are often rendered infertile when the disease is in an active phase [13], and since this coincides with the tupping period, consequential effects on conception rates may affect lambing percentages adversely. Affected ewes may die as the physical stress of late pregnancy increases; they may die in parturition owing to weakness; their lambs may be aborted or too puny at birth to survive; or the ewes may be incapable of providing sufficient milk to rear their lambs. The overall effective lambing percentage of flocks (lambs reared to ewes mated) can be drastically reduced [17]. For these reasons most farmers slaughter the whole or major part of affected flocks, preferring to face an immediate and determinate loss rather than one of unknown dimensions. In the same way affected lambs are usually slaughtered despite light weight and lack of finish. Carcass recovery value of affected ewes and lambs may be zero owing to emaciation or icterus (jaundice).

Economic loss in dairy cattle arises mainly from reduced milk yield. Cows with photosensitive teats and udders cannot be milked at all. Mastitis due to secondary infections and loss of quarters often follow such cases. Affected beef cattle may suffer a severe check to growth or fattening. Mortality rate in cattle is usually low.

While the disease is a serious hazard of the grazing animal over the most intensive livestock producing areas, the impression must not be conveyed that it occurs every year on every farm. Its incidence is sporadic in time, place and severity. Some districts, such as Poverty Bay, suffer very frequently from outbreaks of widely varying severity. In others, such as Manawatu and Wairarapa, occurrence is relatively infrequent, 18 years having elapsed between the severe outbreaks of 1938 and 1956.

In areas where the disease is fairly common, as in the Waikato and South Auckland zones, it rarely occurs on all farms. Even on those where trouble is experienced, it may be confined to a part of the flocks, and the affected animals may be only those grazing particular fields. The disease is a menace to the individual farmer to whom it can assume the proportion of a major disaster. To farmers collectively it has mainly a nuisance value, since either precautions have to be taken or the risk of loss accepted as a farming gamble.

In practice the disease can be prevented by avoiding grazing of any pasture during dangerous periods and providing alternative foods as green feed crops, silage or hay [22]. Over the past twenty years, dangerous periods have always been predicted from current meteorological data. Unfortunately such predictions have erred on the positive side, and anticipated outbreaks have often failed to materialize. Consequently, protective measures have been taken more often than necessary. Since such measures involve significant departures from the normal farming pattern of a dominantly pastoral system, the nuisance value of the disease is highlighted. It will also be obvious that the failure of the disease to appear when officially predicted has led to more widespread acceptance of the risks and consequently much greater national damage when a severe outbreak has occurred.

PATHOLOGICAL ASPECTS

The pathology of facial eczema in sheep as observed in naturally occurring outbreaks has been described in detail by several workers [9, 11, 21]. Considerable variation, both in the extent of liver damage and in clinical manifestation is characteristic. Pathologists are generally agreed that the primary lesion involves inflammation of the medium-size bile ducts and that the disease may be described as an acute obliterative cholangitis (inflammation and destruction of bile ducts) to which other changes are mainly, if not completely, secondary. Essentially such changes which follow rapidly on the obliteration of the bile ducts by fibrous tissue involve ductule hyperplasia, canalicular infarction and hepatocellular necrosis (enlargement of small ducts, invasion by hyaline material, and degeneration of liver cells). Vascular occlusive lesions have also been observed in the portal vein and hepatic artery, while changes in the adrenal gland and spleen have also been noted [12].

Photosensitization has been shown to be due to phyllo-erythrinaemia [3] originating from impaired liver function. In consequence of bile duct occlusion, phylloerythrin (the normal breakdown product of chlorophyll) accumulates in the blood and renders exposed unpigmented skin surfaces highly photosensitive. Although it is well established that the liver lesions precede the onset of photosensitization, quite advanced liver damage may exist without any sensitivity [4]. Bilirubinaemia is almost always found in animals that are photosensitized. Elevated values for serum transaminase and serum cholesterol have also been noted in affected sheep, the extent of the increase over normal appearing, in general, to be related to the severity of liver damage [12].

Macroscopic liver changes in field cases are readily observable. In "mild" cases, as in fat lambs slaughtered at an early stage during outbreaks, damage is confined to a few well-defined patchy areas, lighter in colour than normal (Figures 3 and 4). These usually begin at the liver borders and are found most frequently in the left lobe. They are characterized by a distinct, finely mottled appearance due to duct proliferation, cellular infiltration and fibrosis of portal areas. The lesion may extend deeply into the parenchyma below, and the thickened white oedematous walls of the ducts are readily observed on sectioning. Similar isolated patches may be seen on either surface in any part of the organ. In "moderate" cases the size and number of lesions of this type are greater, but no other gross abnormalities are seen. In "severe" cases the damage is generalized, with the whole surface showing fine mottling. The organ is usually enlarged, is greenish or yellow green in colour, and the gall-bladder is usually distended with bile. The extra-hepatic ducts are thickened and contain inspissated bile which may occlude them. The organ is much firmer than normal in texture and when sectioned shows many thickened bile ducts, often occluded with inspissated bile. In "chronic" cases active changes have ceased. The liver appearance varies greatly, depending on the extent and site of the initial bile duct damage. In types most frequently seen—and these are typical of "severe" cases—the bulk of the original liver has degenerated to a dense fibrous mass while one or more bulbous masses of regenerated liver tissue are present on the visceral surface. The shape is extremely distorted.

Photosensitization lesions likewise vary greatly, but present no unusual features. They may appear within a week or so of the initial liver damage, but may be delayed for several months. The lesions are usually confined to the ears, face, lips and eyelids, but the vulva may also be involved. Initially these areas become puffy and thickened. The ears take on a characteristic droop. Yellow serum-like fluid later exudes to form a hard, dry scabrous covering. Necrosis of the skin occurs. Often the ear tips and sometimes the whole ear sloughs away (Figure 1). Sensitized sheep seek shade to avoid severe irritation. If this is available and the animal survives the general effects of liver derangement, the facial lesions readily heal (Figure 2). In field outbreaks it is uncommon for more than 10–20% of a flock suffering 100% incidence of liver damage to exhibit photosensitivity, though its appearance is usually the first sign that an outbreak has occurred. In ewes with badly affected livers but with no sign of photosensitization or icterus, the disease is manifested mainly by loss of appetite and falling away of body condition, often to the stage of severe emaciation.

THE PASTURE/TOXIN THEORY

The failure of attempts to transmit the disease from affected to healthy animals gave rise to the suggestion in 1908 that the disease was due to "dietetic errors" [16]. Subsequent observations confirmed this belief [9, 33]. Eventual recognition of the essential pathology of the disease as involving liver damage and photosensitization consequent on liver dysfunction, stressed the similarity of facial eczema to poisoning by *Tribulus*, *Lippia* and *Lantana* spp., so that it became generally accepted that a liver-damaging factor or toxin of plant origin was responsible. A toxin hypothesis was supported by the specific nature of the liver lesion which showed no evidence of an infectious cause.

Since more than 20 different diseases in which liver damage and photosensitization were characteristic had been described in various parts of the world, and since in nearly all of these a plant was known or suspected as contributing the liver-damaging substance involved [4], it was natural to suspect a plant as the cause of facial eczema. Careful examination by botanists and mycologists of fields in which the disease had been extremely severe during 1938 failed to disclose or incriminate any weed or fungus. The general close association of the disease with rapidly growing pastures, following warm autumn rains, suggested that the toxic substance was contained in such pastures. The testing of this hypothesis by feeding suspected grass under controlled conditions was rendered extremely difficult by the sporadic occurrence of the disease in the field and the delay that occurs between the ingestion of toxin and the appearance of symptoms. It was found that by the time a particular pasture had become suspect in consequence of the appearance of the disease it was invariably quite "safe" when fed to experimental animals. It was not until 1941 that the typical liver lesion of facial eczema was produced in lambs fed in pens on green grass cut from a field in which grazing lambs had developed the condition [36]. This experiment, though not reproducing the complete facial eczema syndrome, since neither icterus nor photosensitization resulted, was accepted as demonstrating the soundness of the pasture/toxin theory. It marked the starting point of all subsequent work aimed at isolating the liver-damaging principle. It also provided a basis for systems of control involving the removal of sheep and cattle from potentially toxic pastures.

All research over the next 16 years tended to support the pasture/toxin theory, as indeed was almost inevitable in view of the experimental approaches used.

The researches concerned may be briefly summarized. Methods for the detection of toxic periods and location of toxic grass were devised. These involved the sequential introduction and removal for slaughter of lambs on experimental areas which were continuously sampled by mowing [5]. Methods of preserving toxicity of such grass by heat drying were developed [5]. Progress was seriously limited until it was demonstrated by small-animal studies with such material that the livers of guinea-pigs reacted characteristically to the liver-damaging factor [14, 31]. This made available a small-animal bioassay to chemists, whose work hitherto had been seriously frustrated by lack of sufficient toxic material when the only test animal was the sheep.

By 1957 chemical extraction of the poison from pastures of proved toxicity had reached the stage where routine concentrates could be produced which contained one 70,000th of the original dry weight of grass and about half the original toxin level as assessed by guinea-pig bioassay. Occasionally extracts confining the poison to one 200,000th to one 400,000th of the weight of grass were produced. One preparation was obtained with a toxic fraction representing one two-millionth of the grass weight, emphasizing the extremely minute amount contained in the original pasture [41]. The poison was found to be readily destroyed in chemical manipulation, and it was no comfort to discover that fractions of similar weight and physical properties could be obtained from some non-toxic samples of grass, and that comparative work revealed no distinct chemical or physical features associated with fractions of high toxicity. These chemical studies led to the discovery of a substance [6, 32, 35] which, while not the toxin itself, was usually associated with it. As the basis of the so-called "beaker test," this substance provided a rapid and easily applied chemical approach to the detection of toxicity in pastures in the field, and aided the collection of larger quantities of toxic material for chemical and biological study.

All this work added support to the pasture/toxin theory, which was extended to involve the concept that the toxin was probably an aberrant plant metabolite resulting from the effect of unusual environmental factors on pasture growth. The transient behaviour of the toxin in the field lent plausibility to this concept, particularly since pastures apparently became "safe" once cold weather hardened off the lush growth of early autumn.

FUNGAL ORIGIN OF THE TOXIN

It is understandable, in view of the foregoing, that the alternative of a fungal origin of the toxin should have been completely ignored during this period.

From the early days the idea that a fungus might be responsible was commonly advanced, particularly by laymen. This arose from field observations that periods of facial eczema outbreaks usually coincided with periods of prolific fungus growth. The idea was abandoned by research workers, largely because of the failure of the 1938 attempts to incriminate fungi and the success attendant upon pasture experiments of the type just described. Obviously, too, the climatic conditions associated with outbreaks would be expected to stimulate fungal growth, which, in consequence, was dismissed as being merely coincidental.

Revived interest in the possibility of a fungal origin occurred in 1956 in consequence of an offer to the facial eczema research workers of Ruakura, from the soil microbiological team of the Soil Bureau, to include an experimental facial eczema area in its broad survey studies of forest, pasture and soil microbiology of New Zealand [27, 39]. It was suggested that attempts again be made to screen unusual fungi characteristic of eczema-producing pastures. Such appeared worth while, since much more appropriate techniques had become available (guinea-pig bioassay and beaker test) for detecting toxicity of suspect material. In addition, chemical extraction work from toxic pastures had reached the stage where a possible microbiological origin of the toxic extracts had been postulated.

Studies on a facial eczema "hot spot" area commenced in 1957, but almost two complete facial eczema seasons, during which toxic pastures were collected from the area in question, were to pass before success came. In the meantime some 1600 micro-organisms were isolated and cultured from the area. Ten of them (3 yeasts, 5 fungi and 2 bacteria) were selected for intensive study because of their high incidence during the danger periods. The screening of these in some 18 experiments produced negative results [39]. Towards the end of the 1958 season, scrapings from a gang mower, operating during a period when climatic factors and "beaker test" assessments suggested a period of high pasture toxicity, were submitted to "beaker test" assay, with strongly positive results. The dust was found to be composed mainly of spores of a fungus, subsequently identified as *Sporidesmium bakeri* Syd. The same species of fungus had been found predominant in mycelia collected from the same area the week before. This observation of a high beaker test response from material consisting mainly of fungal spores was the first positive evidence suggesting an association between the disease and a fungus [28].

Events moved rapidly; the fungus in question was cultured and a high-sporing strain isolated. Supplies grown on potato/carrot media were fed to guinea-pigs and later to sheep. The guinea-pigs showed typical facial eczema liver lesions, and the complete syndrome involving liver damage, icterus and photosensitization was produced in lambs [27, 29, 38].

It soon became obvious that the liver-damaging factor was much more highly concentrated in fungal cultures than in the most toxic samples of

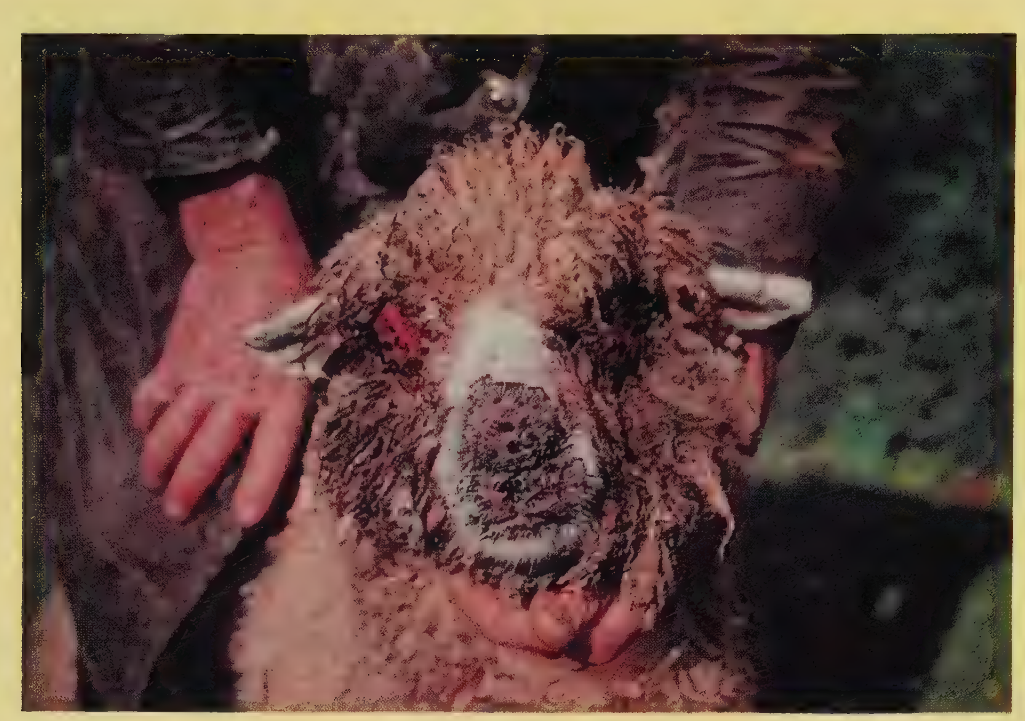

FIG. 1. Clinically affected sheep. Advanced stage, showing severe facial lesions.

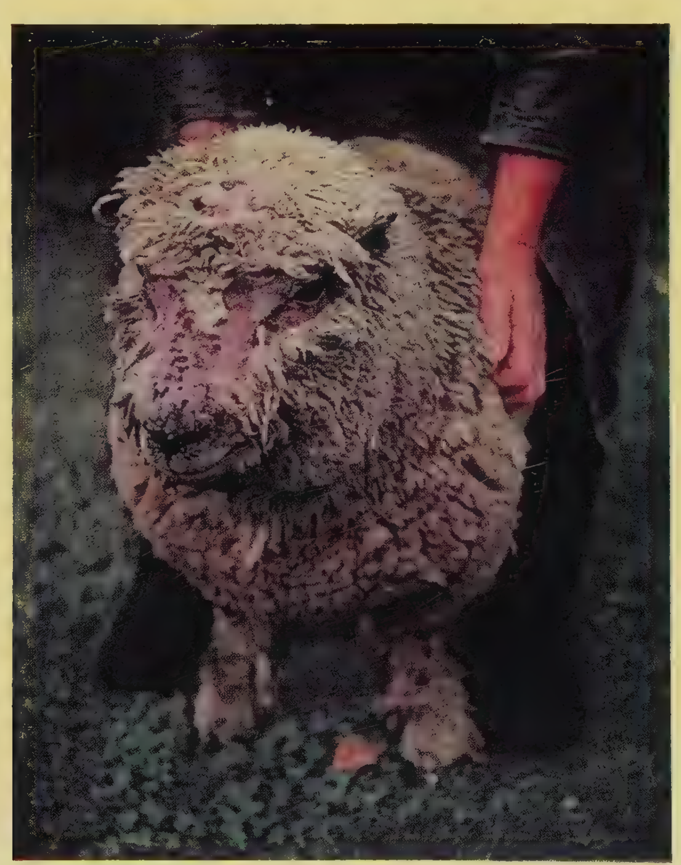

FIG. 2. Southdown ram recovering from facial lesions.

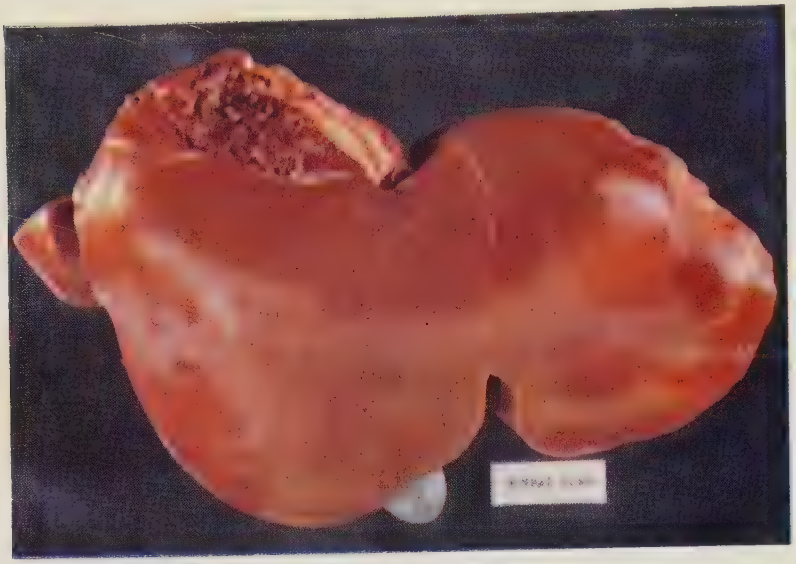

FIG. 3. Normal fat lamb liver.

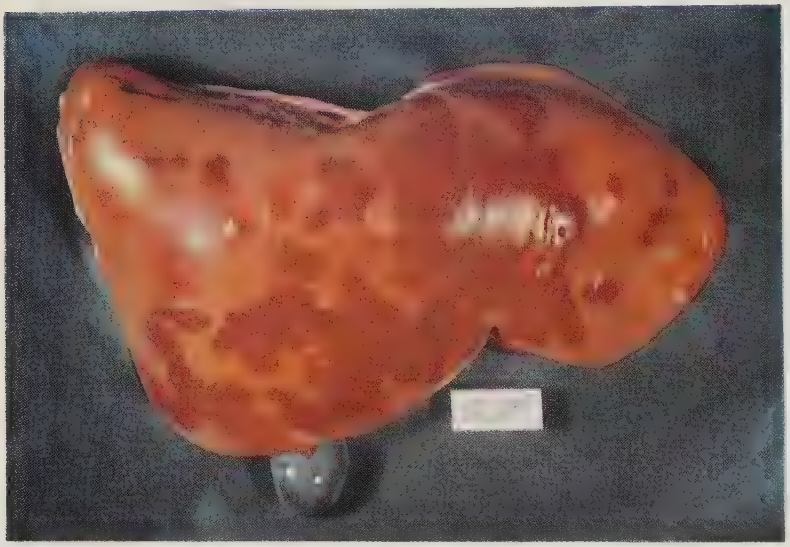

FIG. 4. Affected fat lamb liver, with mottling due to early lesions.

dried grass, and chemical investigations were therefore concentrated on isolation of the toxin from cultures of the fungus. Success was achieved in 1959, when the poison was isolated in crystalline form in combination with CCl_4. Strong chemical evidence was soon forthcoming to indicate that the toxin is a pure substance with the formula $C_{19}H_{20}O_6N_3S_2Cl$. This was named "sporidesmin" [37].

CURRENT RESEARCH

The discovery has changed the whole face of the research. At long last it is possible to produce the disease in the laboratory. For the first time pure toxin can be used to get to grips with the complete pathology of the syndrome from its initial to its terminal stage. Research need no longer be confined to one main centre where the disease occurs most frequently, but can be conducted in any laboratory anywhere in the world. Already ten different research centres in New Zealand are working on specialized aspects of the many problems that remain. Specialist collaborative assistance has been organized in the United Kingdom and Australia. Even in the short time that has elapsed since the initial announcement of 1958, the volume of new information has become extensive and new contributions are coming forward almost daily. In these circumstances what follows must be regarded as an inadequate survey of the present situation.

Broadly, work is being concentrated on studies of the fungus itself, on chemical characterization of the toxin, on the detailed pathological and biochemical relationships of sporidesmin to the animal, and on new possibilities of control.

Sporidesmium bakeri Syd.* is a saprophyte, colonizing relatively fresh debris of a great variety of herbaceous plants. It also grows on damaged leaf surfaces or on the surface of grass leaves in the presence of leaf exudates. Spores are broad, oval and brown in colour, with three transverse septae and measure 18–27 μ by 9–15 μ [39]. While tolerant of wide temperature variations, high temperatures (70–80° F.) and high relative humidities (80–100%) favour germination, growth and sporulation. Under optimum conditions in the laboratory, colonies sporulate three days after germination [1]. The mildest desiccation brings about shedding of spores, which in the field are easily detached by movement and carried by wind. Samples of toxic pasture are freely coated with spores. Field studies have shown the fungus to be widely distributed in both islands of New Zealand. Spore counts, as measured by a volumetric spore trap [2] or direct count [40] on pasture samples, show wide seasonal fluctuations with peaks during summer and autumn under favourable weather conditions. Field incidence of facial eczema has been found to be reasonably highly correlated with such spore counts on some experimental areas [40] but poorly so on others [19], owing probably to the fact that infection of a field by the fungus can be highly localized. It is of interest to note that hitherto this fungus has been recorded only from tropical and subtropical zones.

---

* Likely to be reclassified as *Pithomyces chartarum.*

Many isolates of the fungus have been made [10]. These appear to vary greatly in toxicity [30]. In culture, spores, mycelia and culture fluid, have all contained sporidesmin [7]. The spores provide a convenient source of sporidesmin and large quantities are readily grown on and harvested from rye-corn seed. Spores from this source usually contain about 0·4–0·8 mg. sporidesmin per gramme of dry matter. Deep fermentation so far has failed to produce toxic material.

On the chemical side some progress has been made towards characterization of the toxin, but it is not yet evident what the nucleus is. Evidence from infra-red spectra and chemical studies [42] has indicated that the nitrogens are not basic, and that the methyl groups are attached to oxygen and sulphur as well as to nitrogen. Two alcoholic groups are present. The form of combination of sulphur is still uncertain, but its presence in sporidesmin has made possible the development of a chemical test useful in examining material of fungal origin [34]. This uses the sodium azide/iodine reagent as a spray to detect sporidesmin on paper chromatograms run with water or methanol/water mixtures. Amounts of the order of 0·2 microgrammes can be detected. While this test might detect biologically inactive sporidesmin or its breakdown products, it has so far given good agreement with assays based upon biological activity. The test is not yet suited for use with pasture samples [8].

Pathological experiments with sporidesmin have so far been confined to the rabbit and guinea-pig. These have indicated that the disease can be produced by single oral, subcutaneous, intraperitoneal and intravenous routes of administration. L.D.-50 values of the toxin are of much the same order in the rabbit, irrespective of the route of administration [23]. Less than 100 μg of sporidesmin are needed to produce severe liver lesions in guinea-pigs of 200 g. liveweight.

It has been demonstrated that sporidesmin is excreted in the bile when administered experimentally to rabbits, and that some is reabsorbed by the small intestine and so returned to the liver via the portal system [43]. This could explain the observations that the lesion progresses after administration of toxin has ceased.

Additional bioassays have been developed which are proving helpful in various pathological and biochemical studies. The HeLa cell has been found very susceptible to sporidesmin, and an assay technique based on its use has been developed [25]. The rabbit eye is also very sensitive to the toxin. Its presence in extracts can be demonstrated by applying a small quantity to the surface of the cornea [24]. Both these tests produce results within a few days, compared with the much longer period required by oral administration in the standard guinea-pig bioassay.

On the control side, discovery of the fungus directed attention to the possibility of using fungicides to reduce the incidence in the field. Fungicides shown to inhibit growth of the organism in the laboratory have been submitted to extensive field tests. While significant temporary reductions in spore counts have followed their use, none has given effective control of the disease in lambs grazing experimental areas. This has been the case even when applications at dangerously high levels from the viewpoint of animal health have been made [20]. The high cost of fungicides, their toxicity to stock, and the necessity of correctly timing their application, make it doubtful if this approach can yield fruitful results.

It has been found possible to increase considerably the hazard in suitable seasons by continued frequent mowing and return of litter to experimental areas. Harrowing of pastures has a similar effect. This discovery has increased the chances of worth-while field study of possible control measures. Particular attention is being directed to the possibility of varying pasture management techniques to reduce the incidence of the fungus during dangerous periods. Since any such procedures, however, are likely to offer only an "escape mechanism," the efficiency of which must depend to a large degree on judgment, a much more practical line of attack would appear to be the development of a method of protecting the animal against the effects of sporidesmin. To this end the antigenicity of the fungus and of sporidesmin is being studied to determine the feasibility of vaccination control.

In concluding this brief survey it seems worth while drawing attention to the orderly and sequential advances which have characterized the research so far.

Recognition of the key features of the pathology of the disease was a prerequisite to any advance. The pasture/toxin hypothesis was the natural outcome. Testing of this theory awaited the development of field techniques for the collection of toxic pasture. Chemical fractionation and purification of the suspected toxin could not progress until methods of preserving toxicity in pasture were evolved, and a small-animal assay discovered for the testing of toxic extracts for biological activity. Such studies provided the indirect chemical test for toxicity without which the specific fungus was unlikely to have been incriminated.

At the same time the research has provided yet another example of the way in which new knowledge has often been hindered by an unsound hypothesis. Preoccupation with the idea that the toxin was produced by the pasture plant itself undoubtedly diverted attention from other possible sources for many years. Then again the story presents another example of the way in which an odd flash of inspiration has short-circuited the normal orderly progress of science. But for the fortuitous collection of dust from a mower and its submission to a chemical assay, the systematic testing of the many different micro-organisms associated with pasture could have continued to the stage where the fungal theory might once again have been abandoned. These two latter thoughts have been particularly humbling to the writer who, in his capacity as scientific administrator, has been responsible for the major group working on facial eczema at Ruakura since 1943.

ACKNOWLEDGMENT

In preparing this review my thanks are due to my colleagues for screening the more specialized aspects. In particular I wish to thank Mr. D. C. Dodd, Chief Pathologist, and Mr. N. T. Clare, Chief Biochemist, for their aid and for the photographs used.

REFERENCES

[1] Brook, P. J. (1958). Personal communication.
[2] Brook, P. J. (1959). *N.Z. J. agric. Res.*, **2**, 690.
[3] Clare, N. T. (1944). *N.Z. J. Sci. Tech.*, **25**, 202A.
[4] Clare, N. T. (1952). Review Series No. 3, *Commonw. Bur. Anim. Health.*
[5] Clare, N. T. (1959). *Proc. N.Z. Soc. Anim. Prod.*, **19**, 53.
[6] Clare, N. T., Sandos, J. and Percival, J. C. (1959). *N.Z. J. agric. Res.*, **2**, 108–94.
[7] Clare, N. T. (1960). *Rep. Ruakura Anim. Res. Sta.*
[8] Clare, N. T. (1960). *Rep. Ruakura Anim. Res. Sta.*
[9] Cunningham, I. J., Hopkirk, C. S. M. and Filmer, J. F. (1942). *N.Z. J. Sci. Tech.*, **24A**, 185.
[10] Dingley, J. M. (1959). Personal communication.
[11] Dodd, D. C. (1959). *Proc. N.Z. Soc. Anim. Prod.*, **19**, 48.
[12] Done, J., Mortimer, P. H. and Taylor, A. (1960). *Res. Vet. Med.*, **1**, No. 1.
[13] Edgar, D. G. (1959). *Ruakura Anim. Res. Sta.* Unpublished data.
[14] Evans, J. V., *et al.* (1957). *N.Z. J. Sci. Tech.*, **38A**, 491.
[15] Filmer, J. F. (1958). *N.Z. J. Agric.*, **97**, 202.
[16] Gilruth, J. G. (1908). *Rep. N.Z. Dep. Agric.*, p.188.
[17] Goot, H. (1949). *N.Z. J. Sci. Tech., Sec. A*, **30**, No. 6.
[18] Hore, D. (1960). Personal communication.
[19] Lees, F. T. (1959). *Rep. Ruakura Anim. Res. Sta.*
[20] Lees, F. T. (1960). *Rep. Ruakura Anim. Res. Sta.*
[21] McFarlane, D., Evans, J. V. and Reid, C. S. W. (1959). *N.Z. J. agric. Res.*, **2**, 194.
[22] McMeekan, C. P. (1956). Sheep Farming Annual. Massey Agricultural College, p.21.
[23] Mortimer, P. H. (1960). *Rep. Ruakura Anim. Res. Sta.*
[24] Mortimer, P. H. (1960). *Rep. Ruakura Anim. Res. Sta.*
[25] Murphy, A. M. and Worker, N. A. (1960). *N.Z. J. agric. Sci.*, **3**, 34–40.
[26] Percival, J. C. (1959). *N.Z. J. agric. Res.*, **2**, 1041.
[27] Percival, J. C. (1959). *Proc. N.Z. Soc. Anim. Prod.*, **19**, 27.
[28] Percival, J. C. and Thornton, R. H. (1959). *Nature, Lond.*, **182**, 1095.
[29] Percival, J. C. (1959). *N.Z. J. agric. Res.* **2**, 1041.
[30] Percival, J. C. (1960). Personal communication.
[31] Perrin, D. D. (1957). *N.Z. J. Sci. Tech.*, **38A**, 669.
[32] Perrin, D. D. (1958). *N.Z. J. agric. Res.*, **2**, 266.
[33] Reid, H. A. (1911). *Rep. N.Z. Dep. Agric.*, p.16.
[34] Russell, G. R. (1960). *Nature, Lond.*, **186**, 788–9.
[35] Sandos, J., Clare, N. T. and White, E. P. (1958). *N.Z. J. agric. Res.* **2**, 623.
[36] Simpson, J. E. V. *et al.* (1957). *N.Z. J. Sci. Tech.*, **38A**, 947.
[37] Synge, R. L. M. and White, E. P. (1959). *Chem. & Ind.*, 1546.
[38] Thornton, R. H. and Percival, J. C. (1959). *Nature, Lond.*, **183**, 613.
[39] Thornton, R. H. (1959). *Proc. N.Z. Soc. Anim. Prod.*, **19**, 83.
[40] Thornton, R. H. and Sinclair, D. P. (1959). *Nature, Lond.*, **184**, 1327.
[41] White, E. P. (1959). *Proc. N.Z. Soc. Anim. Prod.*, **19**, 64.
[42] White, E. P. (1960). *Rep. Ruakura Anim. Res. Sta.*
[43] Worker, N. A. and Dodd, D. C. (1960). *N.Z. J. agric. Res.*, **3**, 712–24.

Crop Production and Environment. R. O. Whyte. Second edition. Pp. 392, with line and half-tone illustrations. Faber and Faber, London. 1960. 63s. net.

This new edition is virtually a new book. It retains the title of the first edition and concerns much the same field, namely, the growth and reproduction of crop plants; but whereas the first edition reported on the situation up to 1946, this second edition covers research done between 1946 and 1959. Only one chapter ("pre-dormancy vernalization") is relatively unchanged. The others are almost entirely rewritten, and some concern subjects that have largely developed since 1946, for example leaf area index, and gibberellin.

Dr. Whyte makes it clear that his intention is to provide a general progress report on research, not to attempt a polished and final synthesis. The text is unavoidably somewhat disjointed in places, for it is dealing with rapidly developing subjects. There has been selection of material, but there has not always been time for critical assessment. Indeed, the book has something of the character of an extended review; the contributions of different workers are summarized, often in nearly their own words or with long quotations of up to a page in length; and an indication is given of outstanding problems where research is needed.

The content of the book is not as wide as its title suggests. Dr. Whyte is chiefly concerned with the effects of what he terms the "primary factors" of the environment (light and temperature) on plant development. Other factors, such as soil fertility and availability of water, he considers to be "secondary factors" on the grounds that they do not control development from vegetative to reproductive state; and he does not discuss them. He believes that reproductive physiology is "the central problem of plant science" to which all other branches of plant science are ancillary. Not everyone will agree with this extreme view; but all who read this book must be impressed by its demonstration of the wide importance of developmental physiology in pure as well as applied fields.

The first half of the book is given to basic research. An introductory chapter is followed by chapters discussing the significance, in relation to the change from vegetative to flowering condition, of apical morphology, of synthetic and natural growth-regulating and flower promoting substances, of vernalization, and of genecology and breeding. There are also chapters on the importance of leaf area index in competition for light, and on the construction and use of controlled-environment chambers.

The second half of the book assembles information on the light and temperature requirements of a wide variety of crop plants. The crops are considered one by one, but are classified into three groups: those that are grown for their vegetative shoots (pasture and fodder crops, green vegetables, sugar-cane, tobacco, etc.), those grown for their storage organs (potato, sugar-beet), and those grown for their reproductive parts (florist crops, cereals, oil crops, fruit trees, etc.). In this half of the book academic material is avoided; this is a compilation of recent practical discoveries about methods of controlling development, and it is of applied, specialist interest.

Although this second edition deals with only the increment of research since 1946, Dr. Whyte repeatedly stresses the difficulty of covering adequately the "already voluminous and complex" literature. He suggests, in fact, that this may be "the last time that it will be possible even to attempt to cover the many ramifications and complications within one volume."

The value of this book is that it gives an up-to-date report on this wide and active subject. By its text, by directing the reader to recent reviews, and by providing a bibliography of some 650 items, it will enable those interested in crop and grassland production to get a general appreciation of present knowledge in the field of developmental physiology.

J. WARREN WILSON

The Measurement of Grassland Productivity (Proceedings of the University of Nottingham 6th Easter School in Agricultural Science). Edited by J. D. Ivins. Pp. VIII+217, with line and half-tone illustrations. Butterworths Scientific Publications, London. 1959. 35s. net.

Grassland has long been regarded as that portion of a farm on which the least expense per acre was justified by way of seed, manure or labour. Such a state of affairs is rapidly changing, and many farmers incur an annual expenditure on grassland corresponding to that on their arable crops.

This change in outlook has made it necessary for the farmer to know what extra return he obtains for the extra outlay. In essence he needs to get a measurement of the productivity of grassland under the various treatments he is prepared to adopt. Such treatments may be changes in the rate of application and kind of manure; in the use of special varieties of grasses and clovers as provided by the plant breeder; or even in arranging for the grazing to be controlled.

In arranging for the use of his grassland the farmer has to consider the clash of interest between the animals and the plants. The control may occasionally lead to the grass plant receiving due consideration by way of protection from the grazing animal in order that at a subsequent date the grass may be able to supply the needs of the animal during a more critical period in the animal's life. Thus during the early spring or during a summer drought it may often pay to sacrifice the well-being of the plant for the sake of the animal, but the plant must not be continually penalized throughout the whole year, and year after year, otherwise it will disappear from the sward.

In all this it should be mentioned that even the productivity of the grassland is not the main interest of the farmer but its profitability, which very largely depends on the distribution of the production. Thus though the production as measured by Starch Equivalent per acre may be higher in case A than in case B, if the production of the Starch Equivalent is better distributed in case B than in case A, the profitability of B may yet be higher than A. This is particularly important when the extra grass in March and April brings in the winter price for milk as opposed to the summer price for the extra production during May and June.

Though profitability is the aim of the farmer, the productivity of the grassland has to be measured, but instead of comparing productivity due to different treatments by way of two cuts taken during the flush summer season it is necessary to compare the productivity of the respective swards in each month of the year. This is really where measurement of grassland productivity becomes a problem, and Professor Ivins and his colleagues at the University of Nottingham have done a tremendous service to agriculture by focusing attention on the difficulties of measuring the grass yield per acre when the produce is only at grazing height.

The various contributors selected over a wide field—including friends from overseas—came together in a symposium at the Midland Agricultural College, Sutton Bonington, to put forward their ideas on the subject and discuss the results of their efforts to tackle this problem.

The papers read and the discussions that followed have been published in book form edited by Professor Ivins, a volume that brings the research up to date and available to the grassland farmer in a highly interesting manner.

MARTIN JONES

Micro-organisms in the Soil. A. Burges. Pp. 188, with line illustrations. Hutchinson University Library, London. 1958. 10s. 6d. net.

Books dealing with soil microbiology are sufficiently rare that the appearance of a new one is worth bringing to the attention of all agriculturists. English-speaking students unfortunately cannot refer to a text comparable with Pochon and de Barjac's modern (1957) *Traité de Microbiologie des Sols;* this suffers from the usual French defect of verbiage but, by virtue of its large number of pages, covers the field of soil microbiology very satisfactorily. In English the only detailed text is Waksman's *Principles of Soil Microbiology* which is now out of date (the second and last edition was published in 1932). His more recent (1952) *Soil Microbiology* was compiled largely with the sometimes not too judicious aid of a pair of scissors on his earlier book and is unsatisfactory in many respects.

It is refreshing then to pick up Professor Burges's little book (one of Hutchinson's Biological Sciences Series) and find someone writing "from scratch." The author makes no claim to comprehensiveness and, indeed, such is not possible when the material is encompassed within some 165 pages. There is a distinct bias towards mycology, but this is not surprising since Professor Burges is himself a soil mycologist. He justifies his neglect of some groups of the soil micro-fauna on the grounds that that they are covered adequately in the recent (1955) *Soil Zoology*, edited by Kevan.

The introductory chapter is a very sketchy description of the composition of soil. The author's choice of title for this chapter, "The Soil and its Structure," is unfortunate: to a soil scientist the term "soil structure" is very specific, having a much narrower meaning than that given to it by Professor Burges, a botanist.

The first half of the book is essentially technical, describing as it does the types of micro-organisms present, the forms which they assume and their distribution in the soil, along with a chapter on methods of examining the soil population. The writer manages to convey some idea of the fascinating variety to be found among the teeming hordes of organisms living in the soil.

The second half looks at the ecology of soil organisms—the way in which the nature of the soil environment influences the equilibria between the various groups and, in turn, the role of the micro-organisms in the cyclic systems of the soil which are so important argiculturally, Man drastically influences the soil microflora, both in composition and in numbers, by his agricultural activities, and a short chapter is devoted to this aspect. The final chapter emphasizes that the soil is a system in dynamic equilibrium and that this is particularly true in the case of the soil micro-organisms whose numbers may fluctuate rapidly because of the comparatively short time elapsing between generations.

Although the book is by no means exhaustively documented the 175 references listed do constitute a very useful selection of the papers and books pertaining to this subject. Finally, an attractive feature of the book is its price—a mere half-guinea.

A. W. MOORE

Fertiliser Report and Statistics, 1959. The Fertiliser Manufacturers' Association. Pp. 36, with line and half-tone illustrations. The Fertiliser Manufacturers' Association Ltd., London. 1960.

In the 36 pages of this quarto booklet the Fertiliser Manufacturers' Association have gathered together fertilizer statistics for the U.K. from Ministry of Agriculture, Board of Trade, Rothamsted Experimental Station, O.E.E.C. and their own records, covering the period since the end of the war, with emphasis on the recent 1950s to 1958–59. Tables and graphical diagrams are colour-printed in the interest of clarity.

There are five main sections. The first deals broadly with increases in fertilizer use, in terms of nitrogen, phosphate and potash, and relates these increases with changes in crop acreages and continuing improvements in crop yields. The second differentiates between the use of "straight" and compound fertilizers and shows that the latter now account for 62·9% of total nitrogen, 91·1% of water-soluble phosphate and 85·2% of potash. Increases in total nutrients are recorded for each N.A.A.S. Province in England, and in Wales, Scotland and Northern Ireland, and attention is drawn to the changes in cropping in these areas and for an illustrative county, Lancashire.

The third section introduces the results of surveys of fertilizer practice for 1956–57 and 1957–58, conducted by Rothamsted in conjunction with the N.A.A.S. and the F.M.A., and shows how the primary nutrients were distributed between the important crop groups in the various regions of the U.K. Total plant nutrients were divided as follows: cereals 30%, roots and green crops 36%, temporary grass 16% and permanent grass 18%.

The fourth section compares fertilizer use in the U.K. with that in other O.E.E.C. countries. With one or two exceptions, all countries using fertilizers at higher rates of application than in the U.K. have a smaller percentage of their total agricultural land under grass. In all countries in which fertilizers are used intensively there has been a tendency for phosphate to increase at a slower rate than nitrogen and potash, and a further change in the ratio of nutrients in favour of nitrogen and potash may be expected in the U.K in future.

The fifth section dealing with the latest U.K. figures compares 1958–59 with 1957–58 and shows how the use of nitrogen and potash has continued to advance, together with increased interest in compound fertilizers of rising nutrient content.

Appendices give estimated regional patterns of fertilizer consumption for 1953–54 to 1957–58 and, graphically, crop acreage changes from 1942–45 to 1957–58.

The booklet, which sets a high standard of presentation, must be regarded as a valuable contribution from the industry to farming and farm economics. Fertilizers are now so widely used on such a diversity of crops and at so many different rates that a country's total consumption of plant nutrients does not tell us much. We in the U.K. are fortunate in having not only precise estimates of fertilizer use by counties, compiled by the Ministry of Agriculture since 1952–53, but a detailed survey of fertilizer practice relating to individual crops reaching back to 1941–42. No similar survey appears to exist in any other country for the same period, although limited and not too recent data have been published in the Netherlands and in the U.S.A.

We are indebted to the F.M.A. for providing this mass of useful facts. The collation and publication of later data on the subject will be welcomed.

C. C. TANNER

The Manuring of Coffee, Cocoa, Tea and Tobacco. F. J. E. van Dierendonck. Pp. VI+205, with 4 maps, 21 coloured and 69 half-tone illustrations. Centre d'Etude de l'Azote, Geneva. 1960.

The natural fertility of soils in the wet tropics is not high. In contradistinction to arable agriculture in the temperate zone no system of tropical agriculture has yet succeeded in maintaining, still less in enhancing the fertility of the soil. High and economically satisfactory yields are therefore dependent on the continual use of fertilizers. Particularly during the past decade the benefits of rational manurial practices have been amply demonstrated on a variety of tropical crops.

This book, which deals with four important stimulants, gives an account of the principles that underlie the successful use of fertilizers with special emphasis on nitrogen. Full use is made of the published papers and reports emanating from commodity research stations, departments of agriculture and agricultural associations.

The first section describes the agencies that determine the natural fertility of tropical soils. Though its title, "The Responses of Tropical Soils to Manuring" seems somewhat incongruous, this section makes a number of instructive points. Such are: the error of assuming that luxuriant vegetation betokens high fertility; the conspicuous water-stability of many tropical red-earths; the function of shade as a regulator of the eco-climate; and the limited usefulness of soil analysis and foliar diagnosis in determining manurial needs.

In the succeeding sections each crop is dealt with according to a pattern of treatment which includes a history of the crop, its taxonomy, ecology, and the experimental evidence for nutrient responses. The major arguments and conclusions are summarized in English, French, German, Spanish and Portuguese. A selection of the 800 references are quoted in the text.

The author gives a well ordered review of the principles and practices of fertilizer use. In order to impart coherence to the sections on the individual crops he draws generalized conclusions common to them all. These, one feels, are distinctly speculative. For example, although the natural habitat of coffee and tea lies under tropical forest, the author describes these crops as heliophytes, on the grounds that they give higher manurial responses in full sunlight than under shade. This is too dogmatic. Neither species exhibits the morphological character of heliophytes as described by classical ecologists, such as Warming. It would seem less tendentious to say they are not obligate shade plants, and leave it at that.

Anxiety to underline this conception leads the author to discount too heavily the beneficial effects of shade he has outlined in the opening section. To his catalogue one might add protection from wind and hail, the subsoiling action of roots, and the manner in which leaf fall regulates the carbon-nitrogen cycle in the soil. Recent spectacular responses to fertilizers on unshaded crops have not been evident for long enough to dismiss out of hand the contribution of shade trees to the long-term maintenance of soil fertility. Mulch might be a satisfactory alternative if it were available in sufficient quantity at comparable cost.

This book is nevertheless a valuable compendium to have on one's shelves. The illustrations are excellent both in quality and intent, and the whole book is handsomely produced. T. EDEN

Potato Blight Epidemics throughout the World (Agricultural Handbook No. 174, United States Department of Agriculture). A. E. Cox and E. C. Large. Pp. IV + 230, with line and half-tone illustrations. United States Department of Agriculture, Washington, D.C. 1960. (Price not stated.)

This is ostensibly the first world survey of potato blight, undertaken by two members of the Plant Pathology Laboratory, Harpenden, England, at the instigation of the U.S. Agricultural Research Service and the Department of Plant Pathology, University of Wisconsin, and financed by the Wisconsin Alumni Research Foundation.

It is, however, much more than this. It is an object lesson in objectivity, with its orderly marshalling of facts and precise evaluation of a vast number of field observations made in the course of some twenty years of study. This is supported by wide literature research together with an analytical presentation of personal communications from some 70 experienced plant pathologists in most potato-growing countries of the world.

The need to assess crop losses due to disease on a national basis first assumed prominence in the 1914–18 war and was emphasized on a wider territorial basis during World War II, but accurate methods of estimation were sadly lacking until quite recent years, as instanced by the conflicting statements appearing in agricultural literature throughout the world. Indeed, at the Commonwealth Mycological Conference of 1954 a resolution was passed to Governments urging research into this most important aspect of agriculture. The marked progress that has been made in techniques for the assessment of crop losses since that date was disclosed in discussions at the recent (1960) Conference and is highlighted by this book.

Each potato-growing country is treated separately, but a uniform method of analysis of the crop environment in relation to blight outbreaks illustrates patterns of evolvement on which can be based methods of disease forecasting and control. Much use is made of "Climagrams," ingeniously designed graphs from which most of the important factors influencing the development of blight (i.e. temperature, rainfall, time of planting and time of lifting) for any particular area can be ascertained at a glance and liability to blight predicted. It is emphasized that critical weather periods need defining, especially in countries with an irregular incidence of blight, and that here accurate forecasting is of the greatest benefit.

The methods used in this survey have been devised and perfected by the authors over many years, mainly in Great Britain. Starting with a critical study of unsprayed foliage, they observed degrees of blight attack in relation to crop development and yield at regular intervals during the growing season. The data thus obtained were integrated with climatic factors, particularly the Beaumont scale, to produce "progress curves," to define "blight zones," and to indicate the frequency and severity of epidemics, and where carry-over occurs.

Not content with such a survey, the authors pinpoint phases of little knowledge which, despite intensive research, still exist in the story of potato blight, and suggest no fewer than eighteen lines of investigation which could profitably be followed.

The whole report makes fascinating reading, and the precision with which it has been conceived and presented reveals the early training in engineering of at least one of the authors. The book could well serve as a prototype for further surveys of universally important crop diseases, for instance blue mould of tobacco, downy mildew of the vine, apple scab, and powdery mildews in general. J. C. F. HOPKINS

Diseases and Pests of Ornamental Plants. Pirone, P. P., Dodge, B. O. and Rickett, H. W. Third edition. Pp. XI + 775, with line and half-tone illustrations. The Ronald Press Co., New York. 1960. $10 net.

In the twelve years since the second edition of this well-known and useful compendium was issued a marked change in the outlook of plant pathologists, in the widest sense, towards the control of pests and diseases has taken place. A vast number of proprietary pesticides have appeared on the market, many of which have been merely phonetic variations of a few basic chords, and they have disappeared with equal facility. But the basic chords have represented new thinking, so that there has been a minor revolution in the approach by entomologists and pathologists to the practice of pest control. The advent of organic phosphates and chlorinated hydrocarbons against insects and of the dithiocarbamates and other organic fungicides and of antibiotics in the control of diseases has, by their enhanced cost alone, called for new methods of application, chief of which has been the ever-widening use of low-volume spraying with its concomitant research on droplet spectra and the physics of spraying in general.

All of this seems to be reflected in the new edition of this book in which recommendations for control have been thoroughly revised in the light of present-day knowledge. The general arrangement of the subject matter, the practical approach to descriptions and recommendations, and the semi-popular style follow that of previous editions. The final section on control covers all phases from good cultural methods and sanitation to the use of a range of spraying equipment varying from the giant mist-blower to the latest hand apparatus embodying a minute built-in power unit, and the recommended measures embody the wise admonition, often repeated, that manufacturers' instructions must be faithfully followed. It does seem strange, however, that horticulturists who are advised to use residual and systemic insecticides should have to be told in a footnote (p. 117) that arsenate of lead is the same as lead arsenate.

There is a good deal of repetition in the treatment of cosmopolitan pests and diseases, for example, aphids and *Pseudomonas solanacearum*, but this is almost inevitable to avoid constant reference to the index. Lack of consistency in recommendations such as the control of *P. solanacearum* in petunia, verbena, Helianthus, and Zinnia cannot, however, be explained by differences in host plants. (What evidence is there that the bacteria are seed-borne in Zinnia?)

A few deficiencies in the index are noticeable; for instance on page 112 Bordeaux mixture is stated to be one of the best all-round fungicides, yet there are only two entries, one referring to its phytotoxicity in cool weather and the other giving its place in a compatibility table.

The author apologizes for the use of Latin names of host plants but draws attention to the inclusion of common names in a comprehensive index. He is of the opinion that higher education among his readers should be aimed at, and in the light of his remarks on lead arsenate this is evidently more than a pious hope.

This new edition is of great value to all who are directly concerned with the control of diseases and insect pests of plants, and particularly to advisory officers, whether horticulturists, entomologists, or plant pathologists. It is undoubtedly an up-to-date and worthy successor to the well-known earlier editions, and has been greatly improved in ease of reading and clarity of the illustrations, which are reproduced by photolithography on a dead white paper of heavy quality, and the omission of rules from the margins of the half tones.

J. C. F. HOPKINS

Bibliographie der Pflanzenschutz Literatur, 1953. Edited by J. Bärner. Pp. XLI, + 527. Paul Parey, Berlin and Hamburg, for the Biologische Bundesanstalt für Land- und Forstwirtschaft in Berlin-Dahlem. 1960. (Price not stated.)

At a rough estimate, this volume of the bibliography of the literature on plant protection for the year 1953 contains some 14,660 titles. It is salutory to compare that formidable total with figures of 1416 and 7912 for 1920 and 1939 respectively. That the subject of plant protection has advanced with the years to occupy an essential position in current agricultural and horticultural practice, and to be the basis of an international industry, cannot be denied; and yet one must question the value of this vast outpouring of literature.

Dr. J. Bärner has performed a herculean task in assembling the array and in subdividing its contents under readily accessible headings by subjects and crops, but, save as an historical archive, what is the ultimate use of the work? The volume has been published seven years after the period with which it is concerned, and it is debatable whether the majority of its entries are still valuable from a reference point of view. It is difficult to see the wood for the trees, for many of the entries that pack the pages of this volume are taken from ephemeral literature and carry such titles as "You can't burn out the boll weevil" or "Miller Bill would stymie research," or consist of reported news, such as "Study describes symptoms, control of rose streak."

By being so all-embracing the volume fulfils the criteria demanded of true bibliographies, but surely at the expense of usefulness, so that one wonders whether it was partly compiled for bibliographical reasons alone. It is difficult to see any worth in the perpetuation of material that was written with the intention that it should be read and then consigned to the wastepaper basket—not brought up again in a volume of this authority seven years later. It may be said without serious contradiction that all the salient contributions to the science of plant protection appear in the admirable abstract journals published by the Institutes and Bureaux of the Commonwealth Agricultural Bureaux, and that a bibliography compiled from those combined sources would provide a more usable volume than that under review. The majority of ephemera, including advisory publications of transient interest, are listed in the U.S. Department of Agriculture's *Bibliography of Agriculture* in an up-to-date fashion, although the subdivisions of that monthly publication are too wide to permit hasty consultation.

Let none of this, however, detract from the admiration we must express for Dr. Bärner or from our gratitude to the Biologische Bundesanstalt für Land- und Forstwirtschaft, for despite these criticisms the work remains the best available compendium on the literature of its subject.

D. LEATHERDALE

Printed in Great Britain at THE KYNOCH PRESS, *Birmingham*